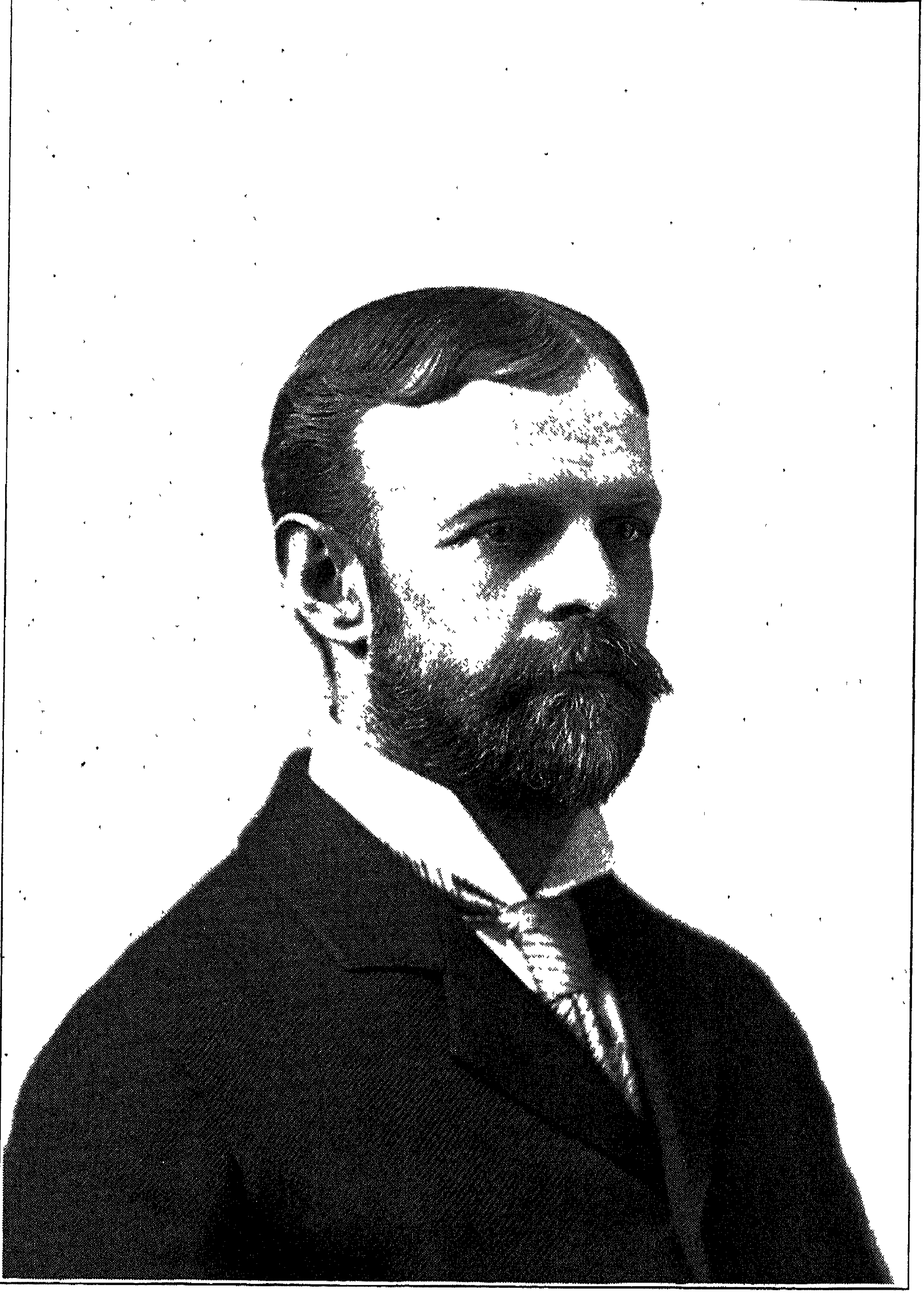

Francis B. Crocker.

GUINDY

TRANSACTIONS

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OF

ELECTRICAL ENGINEERS,

(Established 1884. Incorporated 1896.)

VOL. XIV.

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MAY 18th.
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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, January 20th, 1897.

The 112th meeting of the INSTITUTE was held this date at 12 West 31st Street, and was called to order by President Duncan, at 8.30 P. M.

Secretary Pope read the following names of associate members elected at the meeting of the Executive Committee in the afternoon.

Name.	Address.	Endorsed by.
BATES, PUTNAM A.	Student, Columbia University; residence, 113 West 72d St,, N. Y. City.	F. B. Crocker. Geo. F. Sever. W. H. Freedman.
HERMESSEN, JOHN LOUIS.	Chief of Data Dept., Union Elektricitats Gesellschaft, Kleist Strasse Berlin, Germany.	John B. Blood. Harold Hakonson. F. C. Bates.
HOMMEL, LUDWIG.	Supt. of Construction, Standard Underground Cable Co., Westinghouse Building, Pittsburg, Pa.	Henry W. Fisher. Geo. S. Bliss. Wm. D. Gharky.
KENAN, WM. R. JR.	Chemist and Electrical Engineer, Australian Carbide Co., Sydney, N. S. W.	E. F. Price. W. K. Dunlap. Paul M. Lincoln.
MAC GREGOR, WILLARD H.	Draughtsman, 359 West 27th St., New York City.	Louis Duncan. Frank J. Sprague. C. T. Hutchinson.
RICE, CALVIN WINSOR.	Consulting Electrical Engineer, 8 Eaton St., Winchester, Mass.	C. T. Hutchinson. E. W. Rice, Jr. Louis Bell.
RICH, FRANCIS ARTHUR.	Consulting Mining and Electrical Engineer, Auckland, New Zealand.	Jos. N. LeConte. Clarence L. Cory Jas. A. Lighthipe

STAKES, D. FRANKLIN,	Electrical Expert, The Fort Wayne Electric Corporation; residence, 240 West Washington St., Fort Wayne, Ind.	F. S. Hunting. Thos. Duncan. E. A. Barnes.
TOWNSEND, SAMUEL G. F.	Electrical Engineer in Testing Department, with Ward Leonard Electric Co., Hoboken, N. J.; residence, 131 Fifth Ave., N. Y. City.	Geo. F. Sever. H. Ward Leonard A. W. Berresford

Total 9.

THE PRESIDENT:—The discussion this evening will be on Electrically Driven Vehicles. The subject will be opened by Mr. Riker.

A Topical Discussion at the 112th Meeting of the American Institute of Electrical Engineers, New York, January 20th, 1897. President Duncan in the Chair.

ELECTRICALLY DRIVEN VEHICLES.

(A Topical Discussion.)

MR. ANDREW L. RIKER:—In opening a discussion on electrically driven vehicles, at this time, I feel as if the electric carriage had arrived at a period of transition, that is, it is passing from the experimental into the practical stage. I think that it is generally admitted that the electric carriage is the ideal vehicle, having all the advantages of simplicity, ease of control, freedom from heat, vibration, or odor, but there is one element in the electric vehicle that we must not lose sight of, which has caused all experimenters in this line their greatest trials—that is—the storage battery.

This vital part of the system has been defective, and upon the remedy of this defect depends the success of the electric vehicle. This defect is not that the storage battery is not a practical apparatus, but that it has not been adapted to the particular requirements in this case.

The weight of a motor vehicle must be kept within certain limits To that end the battery portion has had to be lightened and under the same conditions it has had to withstand heavy discharges from 100 per cent. to 1,000 per cent. above the normal rate. To meet these requirements some special form of cell must be devised.

I have corresponded with most of the prominent battery companies both in this country and abroad, and find the best output obtainable for complete cell including hard rubber jar, acid and element, sealed in, is about five and one-half watt hours per pound. This value limits the run from four to five hours on each charge, at a 10-mile pace.

If there is present any representative of the storage battery interests, I should be glad to hear whether they have anything new for this service. I had hoped to be able to give the results of a complete set of tests on a new vehicle upon which I am now engaged, but the carriage is not finished.

My experience with my first two carriages, both of which were supplied with a double motor equipment, has shown that a single motor is preferable. The single motor equipment is much more sightly, and the motor and gears can be placed under the middle of the body and out of sight. The bicycle construction, wire spokes, pneumatic tires and tubular gear I believe are necessary to a successful vehicle. Equally necessary if the vehicle is to give satisfaction, is simplicity of control.

At the present time the electric carriage is not eminently suited for long runs, or out-of-town service, but for this we anxiously await what the future may bring forth.

THE PRESIDENT:—This question of motor vehicles is one of the most important, next to the development of railroad traction, which is before electrical engineers. The success of it depends upon what we can do with storage batteries. Mr. Riker's results of five to six watt hours per pound seems to me better than the ordinary battery will do under the conditions imposed on them. As I have said, tests made by cyclometers show that few vehicles made as much as 30 miles a day, and it is only very rarely that they go as high as 35 miles a day.

The results given in the ordinary battery catalogues show that no battery is now on the market that will drive a motor carriage more than 20 to 25 miles with a reasonable weight of battery. The results as given by Mr. Riker will enable the vehicle to travel something over 30 miles, and I am glad that such results are being obtained. I know myself that there are several batteries that give results better than those on the market, but they have not been developed to that point where they can be commercially exploited. It seems to me that the question is whether some of these batteries can be developed so they will give with comparatively small depreciation a capacity to drive a vehicle 30 to 35 miles. If they can do this they will be a success; if they cannot they will be a failure. If any one in the audience can give us some data on this point I will be very glad to hear it.

May I ask Mr. Riker what batteries he was referring to?

MR. RIKER:—I was referring to the 3-M. chloride battery. I believe they guarantee a thousand discharges on that cell at a three and a half hour rate.

MR. F. RECKENZAUN:—I am hardly prepared to discuss electric vehicles by way of adding new and valuable information on the subject, but I may confirm Mr. Riker's statement to the effect that the best storage batteries available would only give about five and a half watt hours per pound, gross weight. A battery may be constructed to give six, seven or eight watt hours per pound, but it would hardly be considered satisfactory for the purpose in point of durability. In general, I think that vehicles propelled by means of storage batteries could be made a success for short trips—for city work, such as advertising carriages and the like. But for long-distance travel I do not think the time has arrived when it would be worth while to even go into experimenting. The results which have been obtained on the other side with gasoline motors and motors of similar kind are so far ahead of what could possibly be accomplished by means of storage batteries as to practically settle the question in my mind that long-distance propulsion is not a promising field for the storage battery we are now capable of producing.

Mr. Adams:—I merely came here this evening to hear the general discussion on the subject, without making any preparation with a view of giving you any detailed information. The Electric Carriage and Wagon Co. are equipping a station in New York for the purpose of running a dozen or more electric carriages for public and private service in order to demonstrate quickly the commercial side of the question. As this is probably the first station of the kind that ever was equipped, a number of new problems are constantly arising, and it will be some months before we can speak with any degree of accuracy as to what the probable results will be. The service at first will be more or less selective, as we do not propose to try to do impossibilities or impracticabilities. As to what has occurred in the past year I can speak with more confidence. We have constructed a carriage that has travelled 35 miles on one charge through the streets of Philadelphia, no particular route being selected, and the ordinary conditions of city travel, such as grades, railway crossings, and the various kinds of pavements being met with. We have made with this carriage during the past year about 1,000 miles, and have covered this distance with but a single accident, which only caused a delay of about five minutes. The carriage has had to travel over all sorts of streets and roads in Philadelphia, New York, Providence and Chicago. This carriage is in the form of a surrey, and is not adapted for public use. Those that we are now constructing (the first of which is already in New York) are built on the principle of a four-wheeled hansom; that is to say, the front part of the vehicle is exactly the same as the ordinary hansom with which you are familiar, and there is a box extending from the rear on which the driver's seat is mounted, and which box is carried on the rear wheels and intended to carry the battery. We expect to make with these hansoms and coupes from 15 to 20 miles on one charge, which we consider more than sufficient to meet all the requirements of city service. They are not intended to take long trips out into the country, and we will not attempt to use them for this purpose. Almost any point in New York or vicinity can be reached within a radius of 7½ miles from Thirty-ninth Street and Broadway, and on returning from a 15-mile trip it is only necessary to change the batteries, which is an operation requiring but a few minutes, when the vehicle will be ready for another 15 miles. This vehicle weighs about 2,500 lbs. The cells which we use are 44 in number and have a capacity of about 70 ampere-hours at a two and one-quarter hour rate of discharge. That is to say, they will give 30 amperes for two hours and one-quarter, and a correspondingly increased amount for lower rates. As it requires about 25 amperes to run on levels at a speed of about nine miles an hour, it will readily be seen that we will have a capacity of at least 20 miles on levels and 15 miles over any conditions that we will probably meet in New York. The battery, including the rubber jars, acid, and retaining boxes, weighs about 1,000 lbs.

THE PRESIDENT:—I have talked with people who have spent a great deal of time and money on the question of motor vehicles, and who have tried oil, compressed air and gasoline for motive power. Their idea is that it is almost impossible to make a motor carriage that can be turned over to any driver—one who knows nothing about mechanics—and obtain successful results. The heat, the smell and other disadvantages were such that the company referred to, gave up experiments with everything but storage batteries. The most extensive fields for motor vehicles is in large cities, where the batteries can be charged at night and where long trips are not required. The experience with storage batteries has been that if they are never fully discharged, but always have a partial charge, the depreciation is not high and their efficiency is satisfactory. If, however, they are discharged completely, the depreciation is very high and efficiency is low. Now the question, to my mind, is whether we have reached such a condition of affairs that any battery made will allow a motor carriage to be run say 30 to 35 miles and still retain some charge in the battery. I would be glad to hear from any one who has had practical experience with storage batteries as to their present status.

MR. H. B. COHO:—Some years ago I had considerable experience with storage battery cars and found that with our tracks in good condition we could run fifty miles on one charge, but when our tracks were dirty we ran but ten miles on the same charge. I think that if I were intending to use a storage battery carriage I should want to use a meter, which after a certain number of watt hours had been expended, would ring the bell and give warning that it was time to return. I have yet to see the battery, which on one charge I would feel certain of making more than thirty or forty miles with.

THE PRESIDENT:—It depends largely on what you have in your storage battery carriage.

MR. CORSON:—I would like to say that in a motor carriage which I have had the privilege of examining—an electric carriage—I have seen the meter which Mr. Coho describes as necessary, which tells the man to go home.

THE PRESIDENT:—If it is only the driver, I think it is all right. But there may be other people, who wish to go on.

MR. JOSEPH SACHS:—I think a discussion probably of the various features that enter into the construction of a motor carriage in general might be of interest. Mr. Riker, for instance, has built a vehicle possessing a number of very peculiar features, and the discussion of these features and others might be interesting. There is a great deal more than the mere furnishing of power in the successful motor vehicle; and while probably the power may be over 50 per cent., still the other factors are very important.

MR. RIKER:—In reply to Mr. Sachs I would say that there is, of course, a great deal more in the electric carriage than just simply the storage battery. But my object was to see if we could not get somebody in the storage battery line to make an improvement there. We think that the rest of the carriage is all right.

MR. SACHS:—If you look at it from the electrical side.

MR. RIKER:—Of course the horseless vehicle must be built differently from the vehicles we have been accustomed to, drawn by horses. In the first place is is a vehicle that carries its own propelling power and relies on traction to take it over the ground, and there is no necessity, so far as I can see, of building a high vehicle. Our new designs, in fact, call for a low vehicle. We also advocate the use of small wheels, using in our new machine 36-inch rear wheels and 32-inch front wheels. I had hoped to be able by this time to give the data on our new carriage; but as I said before, it is not finished yet, through delays of construction and other causes. But our object has been to produce a small, light electric vehicle that has a range of about forty miles on a single charge of the battery. A vehicle constructed for this work, with a capacity of two passengers and an average speed of ten miles an hour over ordinary roads will weigh, complete, about 1400 pounds. Of course, the principal weight here is the battery. We advocate the use of pneumatic tires and large ones, and the simplest form of running gear—single motor equipment—and we are trying on our new machine a device that is practically on the order of a back gear on a lathe, so that when we strike snow or very heavy grades, instead of taking too heavy a discharge on our battery, we can run our motor at its highest economy and reduce the speed of our vehicle to such a point that we will get the best results. This is all operated automatically, so that there is a simple lever to make all the changes. We also believe that the electric carriage, as Mr. Coho said, has to be operated nearly automatically and to take care of itself. We have tried to make this one so; so that in case a man happens to get a little tired and runs the carriage up against a stone wall or something, forgetting to turn off the current, that the batteries will not stand and discharge and the first thing we know we have a wreck. We have provided a device that takes care of that. Also, in case he gets rattled and forgets to cut off the current and put on the brake, which is sometimes done at close quarters, it will cut the current off and bring the carriage to a stop. I know of an electric vehicle now that is being made in which they are trying to overcome that difficulty of running out of a charge, and in fact I believe they have it arranged so that an instrument on the dashboard indicates when it is time to go home. It shows the amount of current left and the amount of current consumed. The same device, I believe, when in charging, puts the required amount, over and above what has been taken out of the batteries, back; so that the machine can be looked after by anybody, and the question of putting 25% more in than has been drawn out is not necessary. It is attended to automatically. The steering gear in a motor carriage is another point that is sometimes overlooked. There have been a great number of very peculiar devices proposed. I think the general tendency is to adopt the style of hinging the wheels at the hub, or pivoting the wheels at the hub, so that the two wheels turn on their own independent steering head or fifth wheel, avoiding any of the great leverage exerted by a fifth wheel device, in which when one wheel strikes a rock or obstruction it tends to throw the carriage from its course. Our new device is such that we can, in fact, go over an obstruction of three or four inches with one wheel, nothing under the other, without a tendency to throw the wheels whatever.

I do not know what other points there are to bring up. But I think there are some gentlemen here who could give us some interesting data, if not on the electric, on the gasoline vehicle.

MR. COHO:—I should like to ask Mr. Riker whether he has ever made any tests showing what the difference of current was on macadamized and asphalt roads; that is, on ordinary days—not when there is mud.

MR. RIKER:—We have made some few tests in regard to that matter, and we find that on an ordinary Belgian pavement the power consumed is about the same as on the asphalt, and they are slightly less than good macadamized roads. Whether the friction of the large surface of the pneumatic tire on a macadamized road offers more resistance or not I do not know; but it seems to be so—that the Belgian block and asphalt offer about the same amount of resistance to the vehicle.

THE PRESIDENT:—May I ask the advantage of a bicycle wheel instead of an ordinary wheel?

MR. RIKER:—Do you mean instead of a wooden wheel?

THE PRESIDENT:—Yes.

MR. RIKER:—Well, the use that the wooden wheel has been put to has simply been to carry loads, and from the mere fact that every wooden wheel is run with radial spokes, the tendency is, when driving from your hub up, or your axle up, to twist the spokes off. We were using a radial wire wheel and with some tangential spokes to it, but we had an accident one night and we twisted the wheel all to pieces. The tangential spokes did not hold. And I think that in a motor vehicle it is absolutely imperative that wire wheels should be used, for a number of reasons. We are building not merely a carriage but a machine now, and wood, as a general rule, is not very largely used in machine construction. We can get a lighter wheel and a very much more stable wheel with the wire construction, and there is no doubt but that the driving wheel should have tangential spokes instead of radial spokes.

MR. SACHS:—Some time ago I had occasion to look into the general art of motor vehicles, and I collected a lot of data relating to the subject. There are numerous essential features to be considered in the construction of a self-propelled road vehicle, aside from the motor. A great many of these considerations certainly do not refer particularly to the electric vehicle. In broadly considering the motor carriage, if I may consider it in that light under the present discussion, I find that the following features should be taken up: first, certainly, the design of the body, the motor, the gearing unless the motor is directly connected, and I understand there is some work being done in the direction of direct-connected electric motors, the armature being directly connected to the wheel spokes. The controlling mechanism, in which direction electrical devices surpass all others. The disposition of the machinery in the vehicle plays a very important part. The general operation, care and attendance, is certainly most ideal in the electric vehicle. The cost of operation, facility of renewing the power-generating material, and the wear and depreciation of the power element. The disturbing and interfering qualities—these, as compared to other vehicles, are in the electric vehicle practically *nil*. The comfort and freedom from objectionable features to the occupants in the electrical vehicle are also ideal.

The appearance of the vehicle: Mr. Riker's design, considered as a self-propelled vehicle, is certainly very handsome. Speed, grade-climbing ability, weight, and in fact all other elements which enter into a traction vehicle. Safety should come into consideration primarily. And here again the electric vehicle is certainly the most ideal.

As Mr. Riker has said, we cannot follow the horse-drawn vehicle in the construction of a motor wagon, for the simple reason that our problem is a radically different one. We have a traction vehicle and not a vehicle that is pulled or pushed; a vehicle that must furnish its own propelling energy from self-contained power.

Having chosen the general design of the vehicle body and the particular form of motor, the construction of the frame is important; and I find that both in Europe and this country the most advanced workers in this direction have adopted a tubular steel frame construction, somewhat of the bicycle tube type. I also find that there is a tendency, more or less, to devise a separate truck; a truck carrying the motor, and probably in some cases the entire power mechanism, and so equip this truck that it can be fitted with almost any design of vehicle body.

The point Mr. Riker made in regard to a low vehicle is certainly a correct one, because a vehicle that is self-propelling and is required to turn sharp corners, at high speed at times, cannot be top-heavy. It would very soon turn the other end to the ground if there were any high center of gravity. Regarding the power, speed and capacity, I think there has been entirely too much attention paid to the question of high speeds. I find that the public interest has been aroused on the possibility of traveling from one point to another at lightning speed. The electric or any other motor vehicle is not solely intended as a racing machine. I believe there are a great many other uses to be considered, and while I think that probably a very high speed vehicle will be of great value for certain purposes, and while high speed ought to be possible with certain classes of vehicles, the majority of the traveling will be done at probably 10 or 15 miles an hour. I do not consider a large power capacity in the motors, or too much of an ability to climb steep grades at maximum speed or high speed advisable. In fact, the device Mr. Riker has mentioned, similar to the back gear on a lathe, clearly shows that it is essential, even with an electric motor, with its very flexible power capacity above its normal rating—that even with such a motor it is better to apply some low-gear apparatus.

I find that there seem to be many mistaken ideas regarding where to place the most weight. Some inventors seem to have placed the entire weight of the machinery on the steering wheels instead of where it ought to be, and where it probably could be best applied—over the driving wheels.

The question of wheel construction, as Mr. Riker mentions, is a very important one, and the point he brought out is probably the principal one to be considered. The wheel of a motor vehicle does not only support weight and resist side thrusts, but has got to be used as a propelling agent. There is a force applied at or near the hub which must be exerted through the spokes to propel the vehicle, with a tendency to twist the spokes. The majority of inventors and builders have tried to apply the power as near to the rim of the wheel as possible. In fact, I found a device some days ago in which the motor was geared directly to a driving gear on the rim of the wheel, using a very high speed motor. I find that wheels have been built to rotate on a fixed axle; that is, the axle being rigidly attached to the vehicle body; and then I found some in which the entire axle and wheels rotate. Both of these constructions necessitate peculiar designs in the gearing, particularly when a single motor is used.

Regarding wheel tires, I find that pneumatic tires have been almost entirely used, although many of the European vehicles still adhere, particularly the gas vehicle, to steel tires, and in some cases wooden wheels. The peculiar advantage which is claimed for the pneumatic tire is its ability to give that slight flexibility when passing over or striking obstructions directly, or on either side of the point of contact. It is just that slight flexibility which to a great extent prevents the steering wheels from being thrown out of their direction or from the stoppage of the vehicle in a great many cases. With a hard wheel the entire vehicle must be lifted over the obstruction, which means just such an expenditure of energy as is necessary to lift that weight over that particular height. Certainly a great deal of this is given back again when the vehicle drops on the other side, and a vehicle of this kind is continually striking such obstructions to run over. Now with a tire having some flexibility, such as the pneumatic tire, that slight flexibility in the material of the tire only necessitates the vehicle being lifted over a correspondingly smaller height. Side thrust pressure, on the bearing, is also materially decreased thereby.

The steering appliances, as Mr. Riker has stated, have been greatly diversified, and in some cases very little attention seems to have been paid to this particular item, as the fifth wheel method seems to have been retained in some vehicles; principally, however, the earlier types. The main point in the steering device seems to be to make the leverage between the pivotal points of the steering wheels and the point of contact on the wheel tire as short as possible, so that the energy, whether it be manual or otherwise, necessary to counteract that applied at the wheel rim when striking an obstruction, which is continuously necessary in running along a rough road or in steering, is as small as possible. The fifth wheel construction, or the pivoting of the single axle at a point midway between the wheels gives the maximum practical distance between the pivot and the point of contact. The tendency seems to be to use the construction adopted by Mr. Riker; mounting the steering wheels on short axles, each pivoted separately to an axle-tree, close to the wheel hub. In some cases the pivotal point of these short pivoted axles is on a line with the contact point on the wheel tire, so that there is practically no leverage at all to turn the wheel. When steering, this arrangement gives the vehicle a rather peculiar appearance, but this device is certainly most ideal. Front steering wheels are most generally used. There are some advantages claimed for the rear steering plan adopted in some vehicles, but I am not particularly familiar with them. In either case, whether front or rear, the tendency is to throw the weight of the vehicle onto the rear wheel.

Many elements must be considered in connecting the motor to the driving wheels. Many of these apply to the gas and steam motors only. Electric motors are certainly ideal. Nothing better can be hoped for, particularly with a single reduction or possibly direct connection between motor and wheels. In other motors a great many different devices have been used. Some of them may be enumerated as follows: Differently speeded gears upon the main shaft, each individual gear being operated by a separate clutch and a cam lever or similar device for operating these clutches. By shifting the lever you throw in one or the other of the different gears and thereby obtain different speeds, or reverse the motion with the motor running in one direction. Instead of having a number of small clutches, one on each separate gear, one large clutch has been placed on the main shaft, and when it is necessary to change the speed, this clutch is thrown out and the gear shaft or sleeve shifted into another connection with the transmitting gears on the next shaft, and then the clutch thrown into connection again. This cumbersome arrangement is used in the principal European motor vehicles, chiefly in those employing the Daimler motor, which are being built by Messrs. Peugeot Freres, and Panhard and Levassor. Then there are different arrangements of separately speeded belts with either clutches or belt-shifting devices, cone pulleys and belt-shifting devices, loose belts and an idler, consisting simply of the transmission pulley and the power pulley over which a single belt runs, this belt being tightened or loosened by means of the idler, another belt being used for reversing. There are various arrangements of friction rollers and disks, and also a number of hydraulic and pneumatic gears. Some of the hydraulic gears use a pump of some kind operated by a motor, and the pump operates hydraulic motors geared to the wheel.

The brake of a motor vehicle certainly is an important factor. The tendency in this direction appears to be to apply the brake upon some separate brake pulley, upon either the motor shaft or upon some transmission shaft between the wheels and the motor. Braking upon the tires, particularly with pneumatic tires, very rapidly wears the tires and is not to be advised. With the electric vehicle, dynamic braking may be considered, and various electric devices can be devised for braking purposes.

I wish to mention, in view of the fact that we all consider the electric vehicle the most ideal, that there are various vehicles—steam vehicles included—that seem to have attained particular success. I may say that so great an authority as Sir David Salomons has lately taken up and developed a peculiar type of steam vehicle. This vehicle is known as the Serpollet steam carriage, and is most peculiar in its operation, being provided with a boiler of the instantaneous type. The tubes of this boiler consist of very heavy flattened steel tubes which are then jacketed over by an iron casing, and the flat opening of these tubes is probably an inch or two long and probably one-sixteenth of an inch high. The water used for generating steam—the boiler normally carrying no water whatever unless it is in operation—is forced into the boiler. This water is forced into the tubes by the hand pump at first, and steam is instantaneously generated, superheated, and then passes directly into the engine cylinders. After the engine is in motion a small pump forces water into the boiler tubes. As the energy of the motor depends upon the amount of steam generated and consequently upon the amount of water forced into the boiler, the amount of water is regulated by means of a regulating valve, the pump-stroke remaining fixed, and the valve has a by-pass so that the water that is not forced into the boiler passes back again into the reservoir.

Regarding gas motor vehicles, it is unnecessary for me to bring up the various objections that have been urged against such vehicles. I may say that acetylene is being tried by various inventors, and I believe there have been some results obtained.

The bad features of gas vehicles may be enumerated as follows: They are not self-starting. They cannot start with any load. They give only full load and no excess of flexibility, and I think that this is one of the prime defects of gas motor vehicles—the fact that when going at the maximum rated capacity, if a sudden demand is made upon them for an excess of power above that which the motor is capable of, the vehicle stops short unless its momentum is great enough to force it over that obstruction. Certainly, in the majority of cases, probably it will run right over any obstruction that ordinarily will be met with. But there may be cases where bad roads will be struck, and similar instances, where, unless the speed gearing is changed immediately before striking such a place, the motor will stop short and it will be very difficult to start it up. I have noted this action particularly in some of these vehicles, and found that this occurred several times during a recent trip. Certainly the complicated gearing and the power lost therein, and that the motor must run continuously after once started must be noted. If you stop for a time, you have got that continuous running of the motor, pouring forth its fumes and deposits. I think that the promoters of this type of vehicle claim that they will and have already partly remedied this defect.

In engines using the heavier oils, the clogging up of the mechanism by deposits is to be particularly noted, as well as the odors which come from the engine exhaust. I would say, in regard to the many parts and the delicate mechanism of the gas engine, and the fact that an engine of this type ought to be built as heavy as possible for the duty it does, that it seems most peculiar that some of the European vehicles were able to go through the extremely long journeys which in some races in France amounted to hundreds of miles. They had some accidents, but still the same motor held out, with the necessary repairs. Some gas motor vehicles have been built which apparently operate with fair success. The Duryea motor vehicles in this country, and the Panhard and Levassor, Peugeot Freres, Benz and others in Europe, have attained quite some prominence.

I would like to ask Mr. Riker about one point in connection with electric vehicles, and that is this—why he prefers the single motor construction to the double motor construction. Certainly both have their advantages, and it may be interesting to have from him his reasons for using one or the other. I also wish to note that while the storage battery to-day is probably the only method adapted to supply electric energy to the electric motor for this purpose, that probably there may be something done in some other direction. I do not particularly allude to the possibility of generating electric current by direct chemical means or by means of heat or some similar method. We may consider in one sense the electric motor as an excellent, in fact as a prime method of tranforming electric energy into actual mechanical power. If we now devise some better method of actually generating the energy, some combination might be made which would eliminate the storage battery entirely. It may seem like taking away a bad element and substituting something worse; but there may be more in the direction of combining a small dynamo, driven by a gas engine, with an electric motor, than would at first appear.

Mr. Riker:—I do not think Mr. Sachs is probably aware, when he makes the remark about the steam carriage, that Count de Dion, who has probably done more experimenting with the steam vehicle than any other man, in an article the other day stated that he considered, for country work or very heavy work outside of city limits, that a steam tractor, as he called it, would be preferable to a vehicle carrying the motive power within itself. He also went on to state that he considered, after a number of years experimenting on both petroleum and steam vehicles, that he was working on an electric carriage for city work, and that his hopes for the future lay in the electric carriage.

In regard to prefering the single motor equipment Mr. Sachs believes there is a word to be said in favor of both these constructions. I think the greatest point in favor of the single motor equipment is its first cost. Of course, in experimenting, we do not care what our carriage costs—the first one. But when we intend to put a practical commercial machine on the market, we have got to look at what we can sell these carriages for, and there is certainly a great difference between building two smaller motors and one larger one. The efficiency also is in favor of the single motor, and the weight is in favor of the single motor. The regulation can be accomplished with a single motor the same as with a double equipment, grouping the cells and changing it in that way. The only objection to the single motor equipment as compared with the double one is that in case anything should happen to one of the motors, in the case of the double equipment, you have another one to come home with. But we found that the motors very rarely gave out; it was a question of something else—of which we did not have a double equipment.

Mr. Sachs:—I must say that I did not notice this recent communication of the Count de Dion. But I am quite familiar with the class of vehicle that he has been promoting or working on. One vehicle is a very heavy affair; and in another case, a light tricycle. In both cases ordinary steam generators are used, carrying water at all times and a large amount of fuel. I hardly believe success will be attained in this direction for various reasons In the first place, you have the generation of steam constantly going on which necessitates automatic firing. Automatic water feeding is essential, and blowing off steam when the engine is stopped would be absolutely objectionable. The danger of explosions exists to some extent unless all these devices work perfectly. Feeding and regulating the fuel automatically is a very difficult thing to accomplish satisfactorily even with oil fuel. In fact there are a number of other objections that may be brought against this class of vehicles. But when I spoke of steam vehicles I meant the type in which instantaneous generation or similiar boilers are used. I have not any exact data regarding the Serpollet vehicle, but from the information I can gather, this particular type of boiler is being developed, in France particularly, and numerous applications are being made, not only to motor vehicles but for other purposes. The results obtained from this type of steam generator have been excellent. I noticed some time ago in an article appearing in *Electrical Engineering*, written by Mr. Summers, the statement that the results obtained with the Serpollet steam generator very closely approximate those that can be obtained with compound condensing engines.

With this type of motive power, you at once obviate a great many of the objections to steam vehicles, and if the device does not depreciate too severely, is not too expensive, and is safe, as it would seem to be under ordinary conditions, I think that there is more than an ordinary chance of a vehicle of this type coming in for some success. I do not mean to say for a moment that I do not believe that the electrical vehicle in every way, is the ideal, if we leave the question of long distances out of the problem entirely. If we simply want to make a trip about town, or if we want a carriage for pleasure purposes to take a short ride for an hour or so, I do not think there is anything that can surpass an electric vehicle, allowing that a fairly satisfactory battery is adopted. We must however have vehicles to travel greater distances than the ordinary electric vehicle in its present condition is capable of, and I think that steam comes in for more than an ordinary share of the probability.

The Secretary:—It may be of some interest to know that the type of boiler referred to by Mr. Sachs was brought to my attention seven or eight years ago in the form of a model. It was a very simple affair and the whole arrangement was easily understood, but I had heard nothing of it since and I supposed there was some practical objection to it.

We have with us this evening as a guest, Mr. Van Hoevenbergh, who is an inventor of a good many years experience and has taken an interest in this subject, not as a maker of electric vehicles, but as a prospective purchaser. I suppose that he may be a competent critic of electric vehicles as they appear to-day. I think that if he feels at liberty to say anything it would be of interest to the members.

THE PRESIDENT:—Being a customer, Mr. Van Hoevenbergh will probably be listened to with a great deal of attention.

MR. HENRY VAN HOEVENBERGH:—Mr. President, I would say merely that I came to listen to-night, not to say very much. But I have been looking for an electric vehicle for some time, and I have examined particularly into horseless carriages of all kinds. The objections we have heard to-night to them I think may be summed up very easily: In that the steam vehicles are noisy; that they require an engineer of a good deal of experience to take care of them, and that they are very complicated—at least all that have been produced so far have been. The gasoline and naphtha vehicles have been pretty thoroughly tried, somewhat in America and more in France. In one of their races 50 vehicles were entered, and the race was from Paris to Marseilles and return, which was 1,005 miles. The wonder of it was that the greater portion of them made the entire trip successfully, but they ran across quite a number of obstacles that have not been brought to notice to-night. For instance, there were no less than 14 dogs sacrificed to science during that trip. One of those dogs was drawn into the machinery and so thoroughly ground up that the carriage had to be taken aside and thoroughly cleaned, and the bones and head and so forth completely eliminated before it could proceed. Another of the vehicles was charged by an enraged bull, and the engineer was tossed over into a field. Still another one was upset while disputing the right of way with a cow. The two retired from the race immediately. But leaving those out of account, the rest seemed to be very successful. One of them was tried by a member of a New York firm. It made the trip from Albany to New York and return, which practically wore the vehicle out, to begin with. It was said further that it frightened every horse that came within range, besides leaving behind it an odor that could almost be seen; so that naphtha vehicles seem to have to sit down in their turn.

To the electric vehicles, I think, with Mr. Riker and others, we must look for the successful vehicle of the future. All of those propelled by naphtha, steam, or any motive power of that kind, are always going to require very experienced men to handle them. They should really have an engineer and a driver besides, which is entirely impracticable for ordinary pleasure vehicles. But the electric vehicle, perfected as it undoubtedly will be in one way or another, would require just simply a driver, who with one lever, which perhaps he might turn from side to side to guide his vehicle, and depress or lower it to regulate the speed, seems to be the vehicle that is going to be successful.

But there is another little side line that I have been interested in for some time that perhaps may be interesting to some present; that is, for fixed stage lines that go backward and forward every day over exactly the same routes, and that need never diverge more than to one side of the street or the other, the trolley might be adopted with advantage. The great disadvantages so far have been that in the first place there can be no ground return wire, of course. Therefore it must be a double conductor, and the double-conductor trolleys have been anything but a success so far. But it is possible to produce a double trolley vehicle which shall have these advantages; that in the first place it shall require but a single pair of conductors to propel it; that the vehicle shall have the whole range of the road, and that it shall be possible for two vehicles to pass each other on the same set of conductors. I know that sounds something like the train which was proposed by that crazy joker who died in France not very long ago, who proposed to the society of engineers there, in all gravity, a train provided with inclined planes, so that when two trains ran together, instead of knocking each other to pieces, one would simply run over the other, down the opposite side, and go on. That resemblance, however, is only fanciful. In the plan that I propose, the carrier is supported entirely upon one wire; it is clamped to it and runs upon it. It has an arm reaching over to the other trolley wire and making the other connection. One of the trolley carriers runs on one wire and one on the other. When the two come together the flexible arms just simply allow the others to pass, and they go on again, the connection being broken but for a very short time. That has been very successfully tried in laboratory tests; whether it will be a success when put on the road is another thing, although it looks very favorable at the present time. I don't know that I have anything else that would be of interest.

THE PRESIDENT:—I think it is rather important to know exactly what the problem is that is presented here. As I say, I have seen data that showed that the ordinary vehicle in city use and even in country use does not go more than thirty miles a day. So if you can get a vehicle that will run thirty miles in 24 hours, it will fulfil pretty much all that is required. But if anybody has any data about that, I would be very glad to hear about it.

MR. C. E. DURYEA:—It was quite late when I learned of this meeting. It was all I could do to get here, and I did not expect to make any remarks. There are some points presented however, that I would be pleased to take up. In the matter of construction, I wish to say a few words about the truck system. It is, I think, the cheaper plan to put the motor on the truck, leaving the body free. The truck is the handiest place to attach the motor. It is also, I think, a matter of common observation that the new inventor in this line begins by putting the motor on the truck. But a little experience in carriage building, such as could be had by inquiring of some coach or stage builder, will show the inadvisibility of putting the motor on the truck because of the constant vibration to which the necessary machinery for the motor vehicle must be exposed, if so near the ground. For an example of what I mean, a prominent coach builder stated that he had seen a $\frac{3}{4}''$ iron bolt worn completely off by the rattling of the nut which happened to be loose, and yet the bolt was riveted over so that the nut could not fall off. It just jiggled around there until it cut the bolt off entirely. That is a specimen of what constant pounding over the road subjects a truck to. So if we are to build vehicles which will give satisfaction in use, we ought to put the machinery in some more satisfactory place—perhaps not so satisfactory to the user, but necessary in order to have the machine better cared for.

The question of odor is one that has been brought to our attention very prominently in the last few years, because we have been experimenting almost wholly with those odor-making machines—gasoline vehicles, and we have urged several things that we think are quite pertinent. We do not consider a gasoline motor so objectionable, in respect to odor, as the average horse, and we think that is a sufficient answer. We have a motor that we believe makes a less objectionable odor than that behind which the public are riding to-day, and we do not ask the public to ride *behind* our motor. In our vehicles they sit in front of the motor, and if they are behind the motor at other times, it is their fault and not ours. As a matter of fact we are pushing forward experiments in the line of eliminating odor, and we think we will succeed in getting rid of so much of it that it will not be objectionable.

The automatic feature that Mr. Riker spoke of is another point. Two or three times in my life I have needed small power and have been unfortunate enough to have to watch it myself, and I secured some of those things that were automatic—automatic steam engines. They were supposed not to need attention, and the great and peculiar feature I found with them was that when you were not looking at them they went wrong. The minute you turned your back something went wrong; the automatic part failed to work;—it was not automatic; and therefore, I believe, the more you can put the entire machine under the control of an operator the better, making it simple enough so that an ordinary intellect can comprehend the whole thing. We drive horses with two reins. We can drive a horse with one rein. We can drive a horse without any rein. We used to drive our oxen with nothing but a whip. But we find that two reins are better. We find it is better for a man to have a little more control of the animal. And I think the same is true of the motor vehicle—the man ought to have full control of it at all times, and automatic devices are objectionable.

In the matter of wheels—when we took up the motor vehicle problem, we did not wish to introduce any more talking points, or rather objectionable points than we could help. We found that the ordinary horse vehicle had wooden spokes. They had been used ever since Adam, so far as we knew, and were fairly good. We used them simply because we did not want to experiment with steel. I have been connected with the bicycle business a little bit for probably fifteen years, and we have used in that steel wheels almost wholly, and we find that the spokes of the bicycle cause more trouble than any other part, except possibly the pneumatic tire that came in recently, simply because metal does not stand constant vibration as well as something that is more elastic. A wooden wheel will stand more pounding over the road than a metal wheel. I do not care how tight you make your metal spokes, they will rattle loose, unless they are protected by very heavy tires. So, other things being equal, you will find that a wooden wheel will stand up better than a metal wheel. We set our spokes in wooden wheels without any spread at the base of the spoke. In the steel wheels we of necessity spread the spokes out, which places them in a much more advantageous position than the wooden spokes, and gives them an unfair advantage over the wood. If you were to put the wooden spoke in the same position, you would find it all right.

As to the matter of tangential spokes for driving purposes, it will be found that the strain on the spoke in the direction of rotation, due to applying the power, is less by far than the strain on the spoke endwise of the axle—sidewise of the wheel, as you turn a corner suddenly, or slip from one side of the street to the other, and any wooden spoke which will stand the sidewise strain necessary to carry a motor properly will also stand the driving strain applied by the motor. So I think wooden spokes will meet all requirements, and that unless the public demands them, there is no occasion to use metal spokes. I do not say this because we have heretofore put out wagons with wooden spoked wheels, for we have built some metal wheels and they are very good ones. We have not had any that "tied themselves in knots" yet. We have had enough experience with bicycle wheels that tied themselves in knots to avoid using steel wheels for motor wagons. But, personally I do not believe in the metal wheel.

The idea of carrying a gas engine, which is a very compact and convenient form of motor, and with it charging a storage battery which should be used then to operate the motor, so as to get the flexibility of speed desirable, has been used to some extent in street car service. A man by the name of Patton—I believe he hails from Milwaukee—has taken out several patents in that line and used that system to some extent, I believe, without any great degree of success. I do not know whether the fault is with Mr. Patton or with the system. I simply mention the fact.

The matter of recharging is one of great interest, it seems to me, to the public. If you are only going for half-an-hour's ride and can order up the carriage, it does not matter much what system you have, because almost any carriage will run half-an-hour if it is any good at all. But for private use, where a man must look out for that himself, it is, it seems to me, quite a question whether he has to put in several hundred pounds or perhaps a thousand pounds or so of new load, or whether he only puts in a few pounds. In the gasoline wagon, if it is only for half-an-hour or an hour's ride, there is no occasion to change the water supply, because the half-hour or hour's run in the gasoline wagon will not sufficiently heat up the water to necessitate any change or any addition. The fuel supply for half-an-hour or an hour is so small you could put it into your hat. Therefore there is little or no work required to put a charge into the wagon and none to take it out, because the motor takes it out. With the electric vehicle, it is necessary to change the batteries and replenish with new batteries, or else it is necessary to attach some sort of supply, and wait patiently. With the compressed air system of storage it is possible to walk up to a stop-cock, and, according to the popular idea, turn the cock and you are full. But with electricity it cannot be done quite so quick, which is the unfortunate part, it seems to me, of the electric wagon—the necessity of time for charging. We have given some thought to the electric wagon, but the experience of some companies which have spent several hundred thousand dollars in trying to adapt electric storage batteries to street car service has discouraged us, and our own experience with electricity has not been favorable to batteries at any rate.

The question of steam as compared with gasoline or with electricity has seemed to us to be in favor of the gasoline rather than the steam. While it is true that steam is a very flexible means of operating, it takes probably twice the amount of fuel to generate the steam, even with the Serpollet or other instantaneous generator, than it does to get the same power with the gasoline engine, and that being true, the item of expense alone would favor the gasoline, although the expense is not worth much consideration in the motor vehicle. Not only must you have more fuel, but you must have more water, unless you have some form of condenser, and none of which I know are of any account for wagon service. In boat service we can get a condenser because we have water. In wagon service we have no water, especially on a hot day in summer. For that reason gasoline is favored.

Light weight seems to be the greatest desideratum of a motor vehicle. The reason why motor vehicles have failed for the last century is almost wholly because their weight has been so great compared with their power; that they have not been practical; and that which offers the greatest power with the least weight would seem to-day to be the most reliable device, regardless of what it is. Going on that line we have stuck to the gasoline vehicles, because we believe they are by far lighter than either steam or electricity for a given power.

MR. RIKER:—Taking up the subject of Mr. Duryea's first remark in regard to putting the motor in the body of the carriage and not in the truck, I do not think that his judgment is quite sound there. I know that in electric railroads, when they were first proposed, the motor was placed in every conceivable spot. First it was put on the front platform of the car, and then it was put in the middle of the car, dropped down and slid up, and finally ended by being placed right straight on the axle, and that is the accepted design to-day, and I do not think that the electric motor builders or railway people would go back to putting the motor up inside the car or suspending it on the running gear. They would prefer to go right straight down onto the axle. I know of plans proposed and used by some concerns in which they use a spring suspension to do away with jar and vibration, but that is not to save the motor as much as it is to save the rail joints. The pneumatic tire does away with a great deal of vibration, and it would seem to me that it was not the fault of the material or the fault of the mounting so much as it was that the workmanship was not as good as it should have been, to have vibrated that belt off in the manner he stated. I have known such things to happen, but I think it is more the exception than the rule.

With regard to the odor which Mr. Duryea spoke about, I thought that was the thing we were trying to get rid of when we got rid of the horse—that was one of the objections to the horse. We want to get rid of that odor entirely. That was one of the features that the horseless carriage offered—that there were no unpleasant odors connected with it.

As regards an automatic device or an automatic machine, I think Mr. Duryea has lost sight of one of the prettiest automatic pieces of machinery that I know of to-day, and that is the naphtha launch. There is an engine which when once started will run and take care of itself with absolutely no attention whatsoever. All the man has to do is simply to light the fire, turn on his valve and the engine will run until he wants to stop it. There is no need of looking at any pressure gauge or anything else. It is entirely automatic. Now whether such a device can be applied to a motor vehicle without involving a great many difficulties, I do not know. The fact of not having water for condensing purposes—there would have to be some other system used; but it seems to me that a system of air could be used similar to the condensers that are being proposed now and are used for electric lighting stations. The question to my mind is simply in regard to the electric vehicle being a success, as I mentioned to-night in opening this discussion, that the battery was responsible for all the trouble of the electric vehicle, and I think the battery people ought to take the subject up seriously and not treat it as a sort of joke. The storage battery of to-day is not constructed for traction work. It is all very nice when you stand it down in the cellar and light your house or run a large central station, or put it on shipboard, but for traction purposes the type of cell has got to be radically changed.

One of the points Mr. Duryea made was the length of time required to change or charge the storage battery carriage. The time required to change batteries in an electric carriage is about a minute. The batteries slide in on racks, making connections by the simple closing of a switch, and I cannot see any very great objection to that. But I am very greatly interested in some tests now; in fact I made a test to-day on something that looked very promising in the storage battery line. We charged the cell up in three and a half hours at a very high rate, and we discharged that same cell in about two hours and three-quarters with an efficiency of about 65 per cent. This cell, it seems to me, can be so arranged that it will last indefinitely. It is simply a question of the conductor in the positive plate wearing out; and a new one can be substituted. In fact we know that the active material in a storage battery lasts forever. It is just simply that the material becomes loosened from the support plate and falls down into the cell, and I believe abroad they propose picking that material up and putting it back again, and I can see no reason why this cannot be done in a battery for electric vehicles.

Another point that has to be brought up in all these things is what we are going to get for the carriages after we build them. In going over these different subjects we find, so far as we can determine now, that the electric vehicle is the cheapest vehicle to construct, and as the President remarked to-night, 30 to 35 miles is a good range for any vehicle. In fact I believe the large department stores in New York City figure on 25 miles as a day's trip for their delivery wagons. That is the greatest number of miles that they run, and it would seem that such a system as they use might furnish the best data that we could gather on the subject of what the length of a run would necessarily be. In all probability no private person is going to use a carriage that he wants to run over 20 or 25 miles a day. The question of running further is simply a question of putting on some more batteries or making the carriage into a sort of railway train. I think the generally accepted practice is when anybody wants to go in this country over 25 or 30 miles they get on board a train, and they take an express train at that. When they go out for a drive they do not go that number of miles.

I think that the electric carriage to-day seems to have a brighter future than any of the others for its use, and that is for a light pleasure vehicle. Probably for heavy omnibuses and large delivery wagons something of the description of steam or some vapor or probably petroleum engines will be used; but I think for a pleasure vehicle the electric carriage is the coming machine.

Mr. Duryea:—This is a progressive age. One vehicle in par- ular that we can point to has gained its popularity by its speed re than anything else. That is the bicycle. People go out ling on bicycles for pleasure, and ride as far as 100 or even re miles in a day. So that a man who expects to get pleasure driving only at the rate of 25 miles a day is certainly very w in his requirements. We find that men pay high prices for st horses. Why? Simply because they can drive a good dis- nce in a little less time than the other fellow, or because they n drive further than other men. The same with motor ve- cles. If we are going to build vehicles that people will be lling to pay for, they must be capable not only of high speed t of continued high speed. A vehicle that would not cover miles in at least half a day I would not consider worth put- ng out as a motor vehicle, because I would not deem it greatly advance of the horse. I myself have driven 50 or 60 miles en with a single horse, to a light buggy, in a day, without maging the horse, and when a man has driven that distance er a rough country, he is usually anxious to finish the last part the journey pretty quick. We have frequently finished 50 iles in an afternoon and had some time to spare, in motor hicles on New England roads. The exhilaration of coasting wn one of those hills at 20 or 25 miles an hour is second only coasting it on a bicycle or coasting it in winter on a sled. And at is where the price for motor vehicles is to come in—the fact at we can have a great deal higher speed than with the horse. e reason why civilization is displacing the horse is because the rse is too slow. The reason why the horse displaced the ox, a w generations back, was because the ox was too slow. So if e are to build motor vehicles to take the place of the horse, ey must be faster than the horse; and the fact that a vehicle ill travel 25 miles on a business trip is no proof that the motor ust not do more. If it does more, the people will take it and y more for it. That is the way the speed problem looks to me.

In the matter of charging, we work a horse for half a day. If vehicle will not stand half a day's work without charging ain, then it is not properly equipped for capacity. The time charging must not be confounded with the time of changing tteries. It is one thing to take them finally back to the start- g point and be able to slip in another set of batteries. It is entirely different thing to be half a day away from home and ish to be back, and the only thing available a Western Union legraph wire or perhaps some private battery stored around mewhere.

Those considerations have presented themselves to us when- er we have turned our attention towards electric wagons, and erefore we have preferred to use a vehicle which we could load with ordinary stove gasoline, which could be had at most ocery or stove stores, or on a pinch run home on kerosene.

Our vehicles will go on kerosene if it is necessary to do so. We think that is quite an advantage in favor of the gasoline vehicle.

I have never used the naphtha launch itself; but I have used several varieties of launches having automatic steam engines, which, so far as I know, are just as reliable and just as automatic as an engine using some other liquid as a source of heat.

SECRETARY POPE (in the Chair):—The question of delivering and transporting merchandise in our cities, is one of great importance, because we all know, or should know, that it is the most expensive part of the freight traffic to-day. When the Singer Sewing Machine Company moved their factory from New York City to Elizabeth, where they had means of direct shipment from the factory, loading machines directly on the cars, it was found that they could place them in Chicago, in bulk in the cars, for what it cost to put them on the wharf in New York ready for shipment, because they dispensed with boxing and the cost of cartage to the train, and we all know that the cost of cartage is of greater importance than the cost of freight, much as we growl about the latter. We are also approaching the question of individual passenger transportation. We find that what is wanted to-day in our cities, in order to give the best facilities for transportation, is to provide exclusive privileges for bicycles on certain streets, and storage for them where the people work or where they lodge. Then each individual may be independent, a large part of the year, of all other kinds of transportation; and consequently, his own ability to go, as Mr. Duryea has said, a hundred miles a day, would be certainly one of the satisfactions of owning a machine of that capacity, even if a person did not wish to use it to that extent. It is the ability to do a thing of that kind if it becomes necessary, that is satisfactory; not that you wish to go a hundred miles every day, but that you have a machine with which you can go a hundred, or a hundred and fifty miles if necessary. Therefore the machine ought to have that margin in order to meet the demands of the present day.

In regard to getting supplies of kerosene at every point—that is what we hope for in respect to electricity one of these days—that its use will become so universal that wherever we may be, we may have electrical facilities, or current for charging storage batteries. One of the drawbacks to the use of electric heating and electric motors for a great many purposes, is the lack of opportunity for obtaining current in a great many cases. We can see to-day, from the example that is being set at Niagara, and which now obtains at one or two points in the west, notably at Great Falls, Montana, how universal the application of electricity becomes when we have the facilities for obtaining it at every point in the city. This will be the case—how soon, of course, is visionary. But we all realize in metropolitan life how much depends upon the convenience of all these improvements that are being brought to our attention.

[Adjourned.]

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, February 17th, 1897.

The 113th meeting of the INSTITUTE was held this date at 12 West 31st Street, and was called to order by President Duncan at 8.20 P. M.

The Secretary read the following names of associate members elected and transferred at the meeting of the Executive Committee in the afternoon:

Name.	Address.	Endorsed by.
BROWN, ALBERT W.	Assistant Manager of Telephone Exchange, American Telephone and Telegraph Co., 39 Cortlandt St., residence, 27 W. 24th St., New York City.	Harris J. Ryan. Fred'k Bedell. Ernest Merritt.
DINKEY, ALVA C.	Supt. Electric Dept., Homestead Steel Works, Munhall, Pa.	Edw. G. Waters. Ellicott Maccoun. H. A. Foster.
FRANKENFIELD, BUDD	Instructor in Electrical Engineering, The University of Wisconsin; residence, 640 State St., Madison, Wis.	D. C. Jackson. F. R. Jones. John E. Davies.
RIPLEY, WM. HOWE	Student, in Dept. of Electrical Engineering, Columbia University; residence, 605 Lexington Ave., New York City.	Ralph W. Pope. F. B. Crocker. W. H. Freedman.
ROSA, EDWARD B.	Professor of Physics, Wesleyan University, Middletown, Conn.	H. A. Rowland. Louis Duncan. Hermann S. Hering
VAN DEVENTER, CHRISTOPHER	Student, Columbia University; residence, 626 Lexington Ave., New York City.	F. B. Crocker, W. H. Freedman. Geo. F. Sever.
WOODWORTH, GEO. K.	Electrician, Crawford Mfg. Co., Hagerstown, Md.	Harris J. Ryan. Edw. L. Nichols. Fred'k Bedell.

Total 7.

TRANSFERRED FROM ASSOCIATE TO FULL MEMBERSHIP.

Approved by Board of Examiners, Dec. 29th, 1896.

Dawson, Philip.	Associate and Chief Engineer with R. W. Blackwell, 39 Victoria St., Westminster, London, England.
Gibbs, Lucius T.	Manager and Chief Engineer, Gibbs Electric Co., Milwaukee, Wis.
Sprague, Frank J.	Vice-President, Sprague Electric Elevator Co., 253 Broadway, N. Y.
Leslie, Edward Andrew	Vice-President and Manager, Manhattan Electric Light Co., Ltd., New York City.

Total 4.

The President:—The paper this evening, gentlemen, will be by Mr. Howell, entitled "The Conductivity of Incandescent Carbon Filaments, and of the Space Surrounding Them."

Mr. Howell read the following paper:

A paper presented at the 113th Meeting of the American Institute of Electrical Engineers, New York, February 17th, President Duncan in the Chair, and Chicago, February 24th, 1897.

CONDUCTIVITY OF INCANDESCENT CARBON FILAMENTS, AND OF THE SPACE SURROUNDING THEM.

BY JOHN W. HOWELL.

The first part of this paper, which relates to the conductivity of carbon filaments, is in the nature of a discussion of a paper read before the INSTITUTE by Prof. Anthony, at the May meeting in 1887.

Prof. Anthony spoke of a change from negative to positive of the temperature coefficient of some carbon filaments which he had observed. He illustrated the change by a figure, which I will reproduce here for reference. (Fig. 1.)

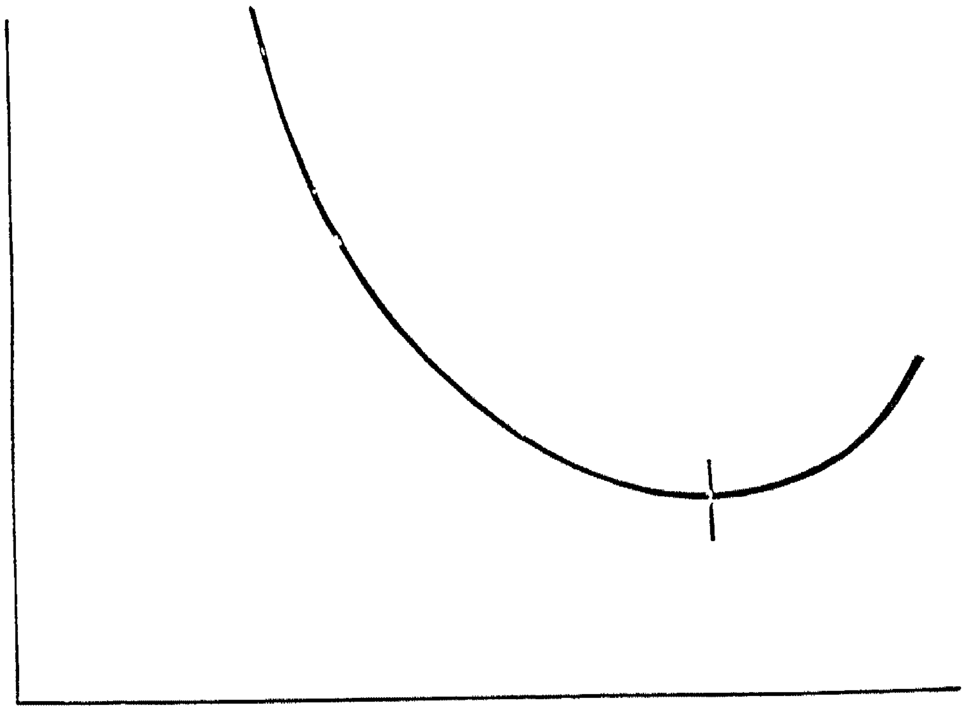

FIG. 1.

Prof. Anthony stated that this change did not occur in all filaments, and that he was unable to explain the circumstances under which it did occur.

Prof. Elihu Thomson, in his discussion of Prof. Anthony's paper, said that he had observed the same phenomenon, but had not investigated it sufficiently to explain its cause.

About four years ago an inventor offered to the General Electric Company a method of coating carbon filaments with metal, claiming thereby a very great improvement in the performance of the filaments. The metallic coating was applied by heating the filament to high incandescence in the presence of the vapor, which was obtained from a very thick dark colored liquid, the application being made by the same means as is employed in the ordinary hydrocarbon flashing process. The proof which he gave that his filaments had a metallic coating was the fact that the resistance of these filaments was lower at about red heat than it was at higher temperatures.

In order to test his assertions, I treated a number of filaments with his dark liquid, and, for a comparison, treated in exactly the same manner a number of similar filaments, using ordinary gasoline. To the surprise of both of us, the gasoline filaments showed the same rise in resistance, after passing the dull red temperature, as was shown by the filaments supposed to have a metal coating. This fact led me to investigate this phenomenon.

I had previously made resistance curves of a great many Edison lamps, which had filaments made without hydrocarbon flashing, and I knew that the filaments of all these lamps continued to fall in resistance to the highest temperature which they would stand. As we had very recently adopted the hydrocarbon treatment upon our filaments, I associated the change in the resistance curve with treated filaments. The filaments which I have previously described as having the reverse curve, were quite heavily treated. I now made a set of ten lamps with various amounts of treatment, all made from similar base filaments. These lamps had filaments the resistances of which, when cold, were 90, 80, 70, 60, 50, 40, 30, 20 and 10 per cent. of the cold resistance of the original base.

I found upon plotting the curves of these filaments, that the untreated filament fell in resistance as it was made hotter, and that this fall continued to the highest temperature at which I dared run it.

The slightly treated filament fell in resistance more rapidly than the untreated filament at first, and less rapidly as the high temperatures were reached, its curve finally rising above that of the untreated filament. As the amount of treatment is increased, the curve falls more and more rapidly at first, and less rapidly at the higher temperatures. When we reach the filament treated to 50 per cent., we find that it falls rapidly to about 50 per cent. of its cold resistance, and remains practically constant at higher temperatures. The curves of filaments treated to less than 50 per cent. all rise after reaching their lowest point, which is reached at about 50 per cent. of their three watts per candle voltage.

These curves show the changes in resistance of these filaments. The ordinates are percentages of the cold resistances of the various filaments, so that all curves start from the 100 per cent. mark. The abscissæ are percentages of the voltages at which the various lamps take three watts per candle. The bottom curve on this sheet illustrates the resistance curve of a carbon filament which had been treated to about one per cent. of its original resistance. This made a filament which was nearly all treatment. This curve shows an increase in resistance from its lowest point to the last point obtained, of about 25 per cent.

This lamp was measured at the Edison Laboratory by Mr. Kennelly and myself. The readings were very carefully taken upon very sensitive instruments, and there can be no doubt as to the accuracy of the curve, as it agreed very well with the measurements I had previously made upon the same filaments. These curves can be obtained a good many times from the same filaments, so there is no permanent change in the filaments which in any way accounts for the rise in resistance. The cold resistances of the filaments, after being measured, were found to be the same as before any measurements were made.

These same ten carbons were taken from the lamps and put into a baking oven, the temperature of which could be regulated very nicely by an electric heater. These filaments were heated to about 500 degrees Fahr., the temperature being measured by two mercury thermometers. The resistance curves obtained in this way are shown on the upper part of the sheet, and agree quite well in character with the resistance curves obtained by measuring the volts and amperes of the lamps, so there is no doubt that the changes in resistance are due to temperature, and to nothing else.

I then obtained untreated base filaments from as many kinds of amorphous carbon as I could obtain, and plotted their resistance curves.

I tried filaments made of bamboo, silk, cotton, cellulose (made by the ordinary squirt process), tamadine, and paper. All of these base carbons gave the same curve, and all of them continued to fall in resistance as long as I was able safely to increase the temperature.

These carbons were quite different in their physical characteristics. The silk filaments were the most porous, and had the roughest and the best heat radiating surface, while the tamadine filaments were very dense and had a very highly lustrous surface.

I was entirely unable for a long time, after making these curves, to come to a satisfactory theory regarding them. The reverse curve is not caused by changes in the characters of the surfaces of the carbons, due to emissivity, because no corresponding changes in emissivity occur.

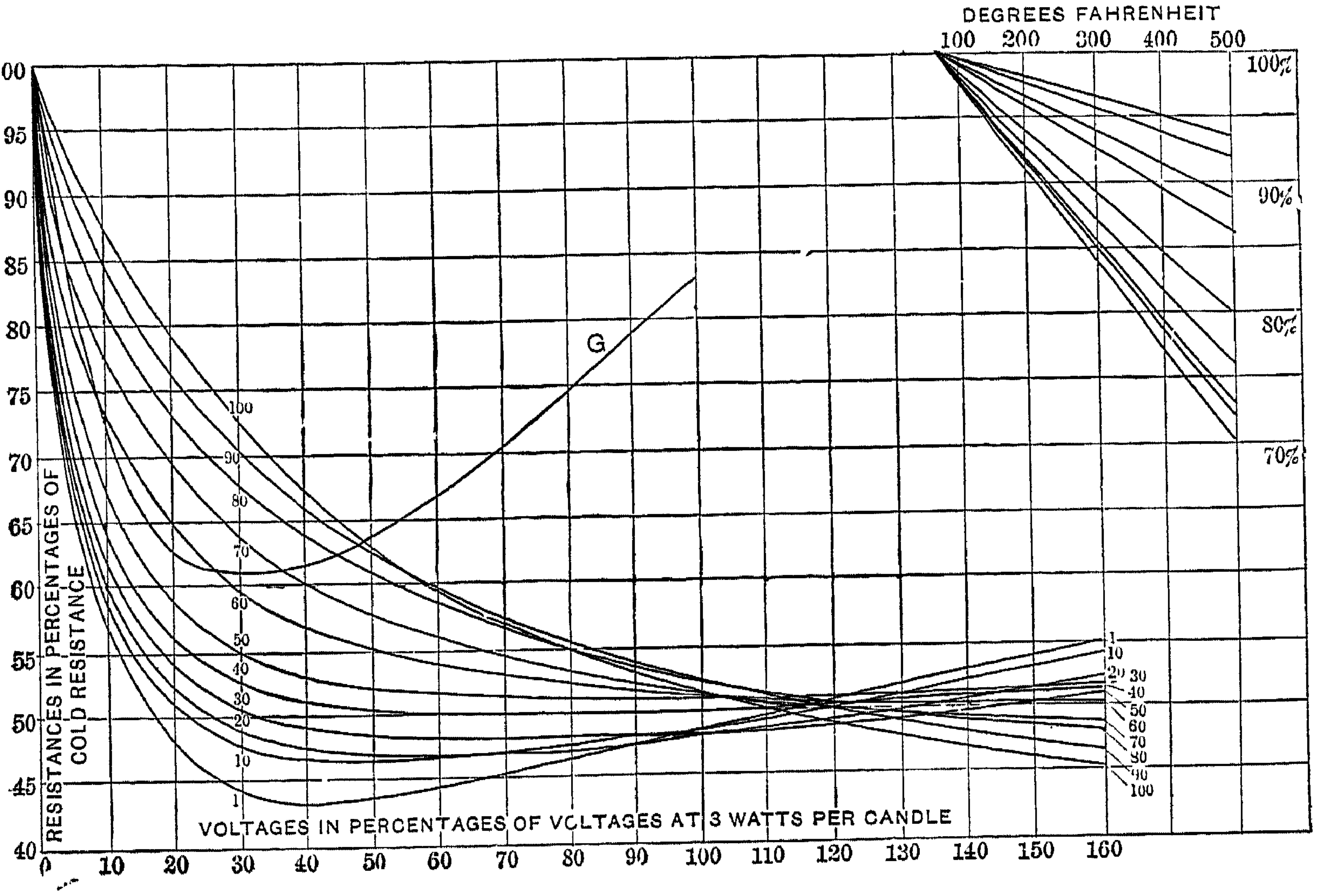

Fig. 2.—Curves showing changes of Resistances of Lamp Filaments with Voltage and Temperature.

I made observations upon untreated and heavily treated filaments, to see if they acted differently in regard to their expansion with heat, thinking that possibly the changes in the resistance curve may have been caused by a change in the expansion curve with temperature. These observations were not very refined, being simply observations made by means of a telescope, but they showed clearly that all of the carbons expanded with heat, and apparently there was no difference in this respect.

It has been the custom for some time to speak of the carbon which is obtained by the treating process as graphite carbon, and knowing that Mr. Edison had, in 1881, made some filaments of graphite, by pressing the pure graphite under very great pressure into the form of loops, I was very anxious to obtain a lamp containing one of these filaments, to see whether it would have the same resistance curve as the other forms of untreated carbon. I have very recently obtained one of these lamps from Prof. Barker, of the University of Pennsylvania, and upon plotting its resistance curve I was very much pleased to find that it had the same characteristics as the heavily treated filament. It reached its minimum resistance at a dull red heat, and from this point, as the temperature was increased, the resistance increased also. This curve is marked G upon the sheet on which the other curves are plotted.

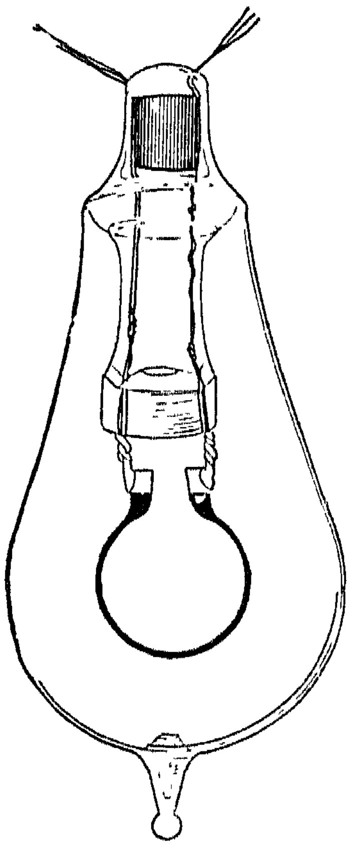

Fig. 3.

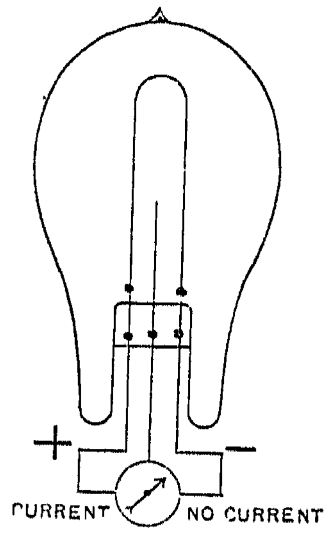

Fig. 4.

It will be observed that the resistance curve of this filament does not fall as much as the other curves, and rises much more. This may be due to the different natures of the two kinds of graphite, or to structural differences. The top of the loop of the graphite filament got much hotter than the rest of it; this would cause this part to start rising before the rest had ceased falling in resistance, and this may account to some extent for the less total fall in resistance of this filament. The resistance of this filament, after the measurements had been made, was just the same as before they were made. This indicates quite clearly that our calling the treated carbon "graphitic" is correct, and that the change in the resistance curve of treated filaments is due to the graphitic nature of the layer of carbon which is put on during the treating process.

The graphite filament lamp referred to is shown in Fig. 3.

The second part of this paper, which relates to the conductivity of the vacuous space surrounding incandescent filaments, may be considered as a discussion of the paper upon the "Edison Effect" in incandescent lamps, which was read before the INSTITUTE by Professor Houston, in October, 1884, and which was the first paper read before this society.

"Edison Effect" is the name given to the effect produced by those currents, first observed by Mr. Edison, which pass from one leg of an incandescent filament across the vacuous space to the other leg, and which can be observed by connecting a galvanometer between the positive lamp terminal and a wire sealed into the bulb and projecting into the vacuous space.

Figure 4, which is taken from Professor Houston's paper, serves to illustrate Mr. Edison's original experiment. The galvanometer indicates a current flowing from the positive lamp terminal through the galvanometer and third lamp wire, and through the vacuous space to the negative leg of the incandescent filament. If the external connection of the galvanometer be changed from the positive terminal to the negative terminal, no current will flow through the galvanometer. This effect can be observed in the most highly exhausted lamps. A lamp so highly exhausted that it shows no glow when tested with an induction coil, giving a spark $\frac{3}{4}''$ long, will allow a current sufficiently large to show plainly on a not very sensitive galvanometer, to pass through its vacuous space. This current increases as the temperature of the filament is increased, but in a well exhausted lamp is never greater than a very few milliamperes, when the lamp is burned at about $2\frac{1}{2}$ watts per candle.

In 1884 Mr. Preece secured from Mr. Edison some lamps having wires sealed into the bulbs, and read a paper before the Royal Society describing some experiments made upon them, illustrating the "Edison Effect."

Professor Fleming read a most elaborate paper before the Physical Society of London, in March, 1896, upon this same subject. Professor Fleming's experiments proved that in well exhausted lamps the vacuum is not a conductor in the ordinary sense of the word, and that the current which passes through it is carried by negatively charged molecules, which pass constantly from the negative leg of the incandescent filament to the positive leg and to any inserted wire, thus bringing the inserted wire to the same potential as the negative leg. Professor Fleming also proved that these molecules pass in straight lines, and that their passage is completely or almost completely stopped by a glass or mica screen placed between the negative leg and the inserted wire. The following experiments serve to illustrate these effects:

Figure 5 shows a lamp having a glass tube surrounding one leg of the filament, and a wire sealed in the side of the bulb, which projects into the centre of the vacuous space. When the leg of the filament which is in the glass tube is made positive, and the filament heated to about a 2½ watts-per-candle temperature, the galvanometer, which is connected between the wire and the positive lamp terminal, shows a strong deflection, but when the leg in the tube is made negative, the galvanometer, being as before connected between the wire and the positive lamp terminal, shows no deflection.

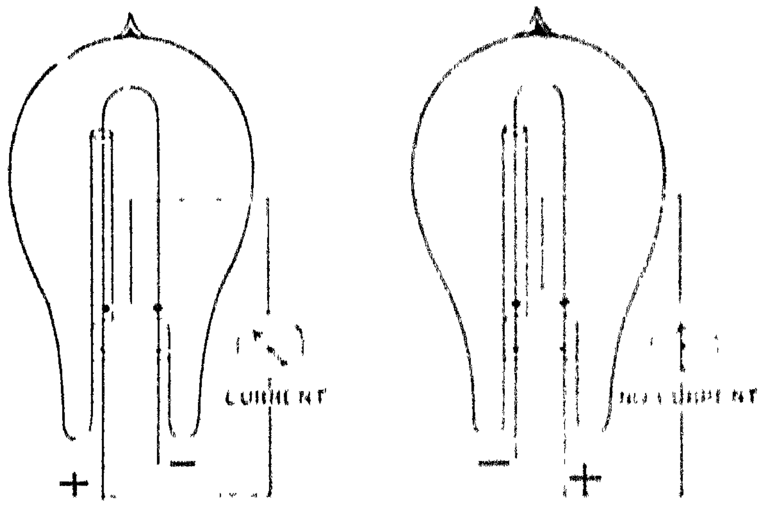

FIG. 5.

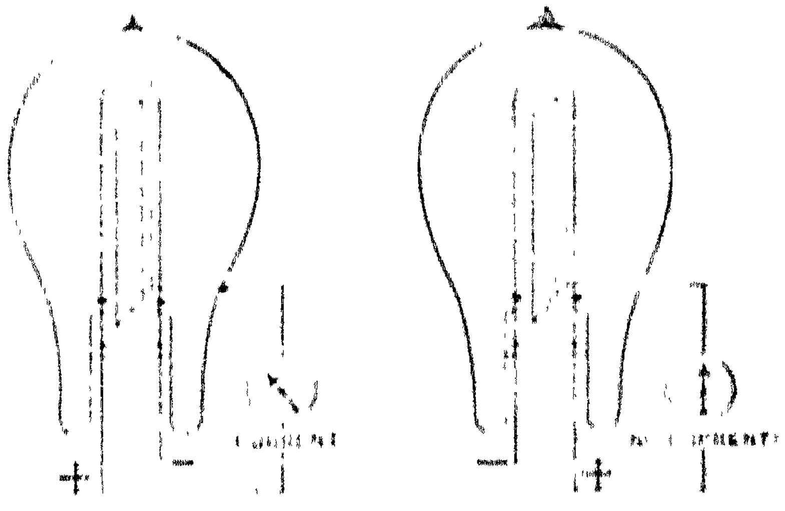

FIG. 6.

Figure 6 shows a lamp having a platinum plate 2¼″ long and ¾″ wide between the legs of the filaments, and a wire inserted in the vacuous space. I also used lamps having a similar plate made of glass, similarly placed. In both of these lamps, when the vacuum was high, no current was produced between the wire and the positive terminal when the wire was shielded from the negative leg; but shielding the wire from the positive leg made no hindrance to the passage of the current. The facts that no current flows when the galvanometer is connected between the negative terminal of the lamp and the inserted wire, and that a shield between the positive leg and the inserted wire has no effect upon the current, show that positively charged molecules are not emitted by the positive leg; while the screen effects just described show that the negatively charged molecules pass in straight lines.

The facts, then, are these: The galvanometer indicates a current flowing, as we designate the direction of currents, from the wire to the negative leg; while experiments prove that the charged molecules which carry the current actually pass from the negative leg to the wire. These facts are entirely in accord with the results obtained by Crookes and others in their investigations of currents in high vacua.

If an alternating current is used to render the filament incandescent, the galvanometer will indicate a current with the connection made to either lamp terminal, because both are equally positive. The current thus produced is a uni-directional one in the galvanometer, and illustrates very well the uni-lateral conductivity between the incandescent filament and the wire.

Mr. Preece states in his paper that lamps which show a blue glow in the vacuous space give stronger "Edison Effects" than those which do not show it. Professor Fleming also observes that poorly exhausted lamps give slightly greater effects, but neither of them paid much attention to these lamps.

The blue glow in lamps has long been associated in my mind with a condition of the vacuum which makes it a conductor. Lamps in the process of exhaustion, just before the vacuum is perfected, show this blue very plainly, if a little more than normal current is sent through the filament. The blue increases as the current is increased and becomes very dense at very high temperatures. This blue indicates a current passing from one leg of the filament across the vacuous space to the other leg.

I observed several years ago, that at a high temperature .04 or .05 of an ampere more current flowed through a lamp showing a good blue than through the same lamp, at the same voltage, when the blue had disappeared. I concluded that this extra current flowed through the vacuous space between the legs of the filament.

If a direct current about 20 or 30 per cent. greater than the normal current be passed through a lamp filament when the vacuous space shows a blue glow, the positive joint between the filament and the platinum wire gets red hot, while the negative joint remains cool.

I have always considered this as proof that the resistance to the passage of a current through a vacuous space was chiefly at the surface of the positive electrode, as the energy was chiefly developed there. If an alternating current is used, both joints get equally hot.

If a lamp be burned at normal incandescence with a direct current, when the vacuous space shows a good deal of this blue, the negative leg of the filament becomes coated with a carbon soot. This effect can be obtained in a few minutes if the blue is dense and the filament is run above a normal incandescence. This I have considered to be due to an electrolysis of a hydrocarbon gas in the lamp.

The lamps which show only a slight amount of this blue glow, if burned at normal incandescence, will not show this carbon soot perceptibly, and the blue will entirely disappear if the lamp is burned for a few hours. This blue is caused more by the character of the residual gas than by the degree of exhaustion. Lamps having a residual of bromine vapor do not show it at all, neither do they show any "Edison Effect." I have seen ordinary lamps ready to be sealed off the pumps which showed blue and then no blue, and blue again, at regular intervals of a few seconds. Such lamps show corresponding changes in the "Edison Effect."

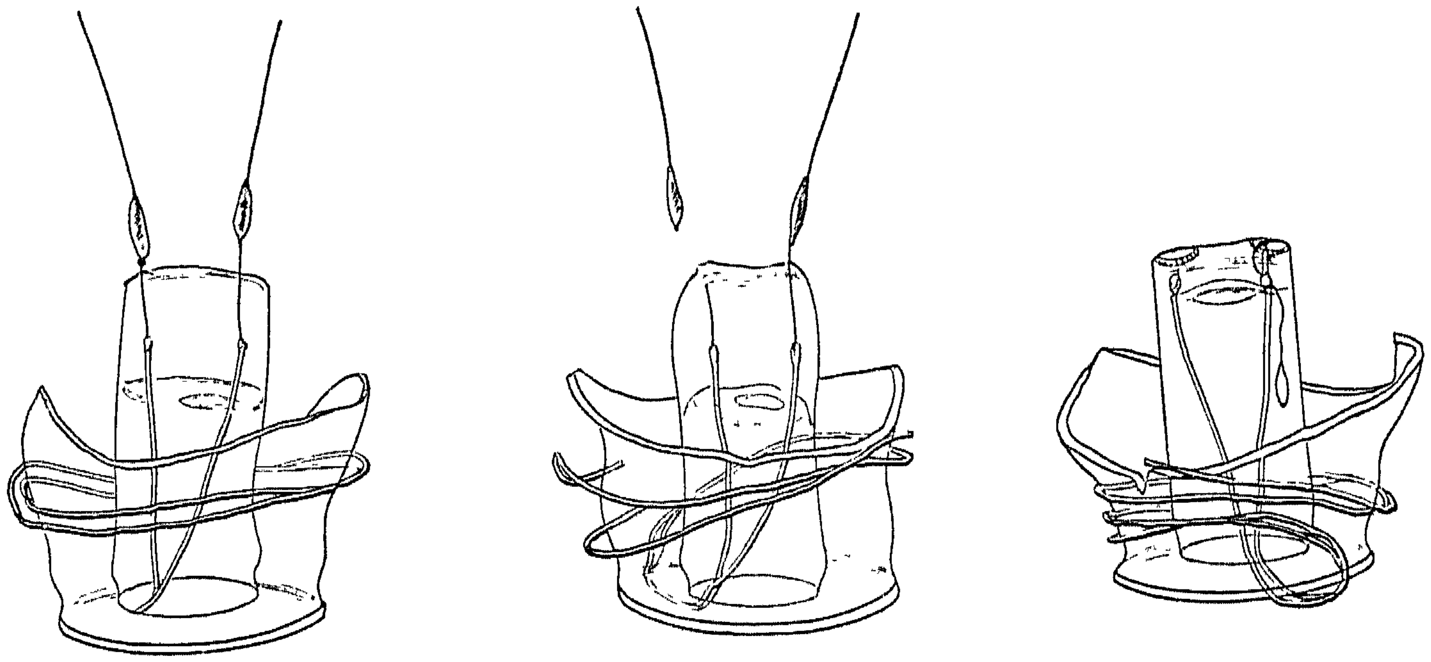

FIG. 7.

If the current be gradually increased in a lamp which shows good blue, the positive joint will get hotter and hotter and finally its platinum wire will fuse. At this stage the resistance to the flow of current across the vacuous space is not great, and if the conditions are such that at this time all the resistance in circuit with the lamp has been cut out, so that the current flowing will be practically determined by the resistance of the lamp and the leads, enough current will flow through the vacuous space to fuse the platinum wires, which are sealed in the glass. This fusion is not due to the same cause as the fusion of the positive joint wire by the vacuum current, because it fuses both positive and negative wires, while the vacuum current fuses only the positive. This fusion of both wires is due to the fact that the low resistance of the vacuous space allows more current to pass than the platinum wire can carry. This is further demonstrated by the fact that a 10-ampere fuse in the circuit will often blow when this happens.

In order to measure the currents which pass from one leg of the filament to the other across the vacuous space, I measured the current at a given voltage of a number of lamps; first when the lamps showed a good dense blue, before they were well exhausted, and again after the same lamps were well exhausted and showed no blue. Some 55-volt 24 c. p. lamps showed .4 of an ampere more on the first reading than on the second. All of this .4 of an ampere must have passed through the vacuous space, for the resistance of the filament remained practically unchanged or became a little lower during the operation.

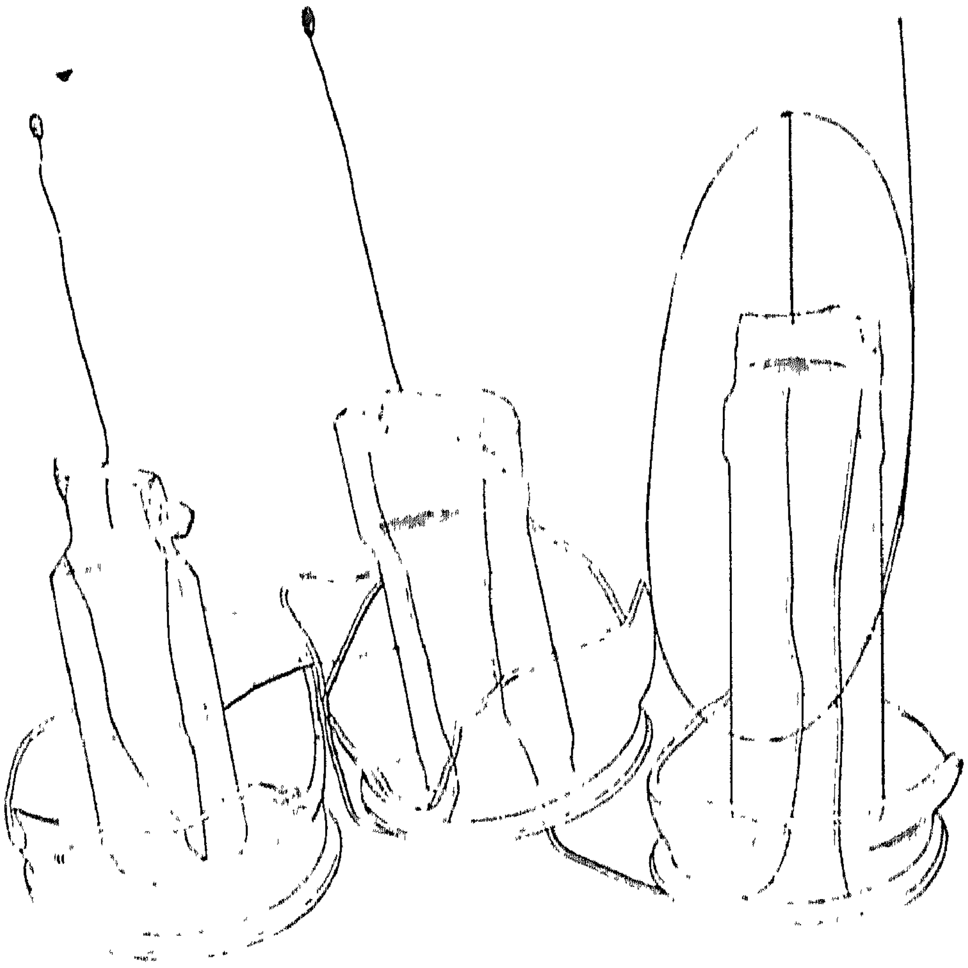

FIG. 8.

I also measured the currents which passed across the vacuous space, when these currents were large enough to fuse the joint wire, and also when they were large enough to fuse both platinum leading-in wires. I found that from one to five amperes passed across the vacuous space when the positive joint wire only was fused, and that when both wires leading through the glass were expanded so by the heat of the current that the glass was shattered, the current measured from 10 amperes to more than 25 amperes.

In order to measure the instantaneous current which shattered the glass, I raised the hand of the ammeter to successively higher points, to find the mark at which the current would just raise the pointer. I used an ammeter measuring 25 amperes, and when the pointer was raised to the 25 ampere mark the current through the vacuous space caused it to jump beyond this mark.

Figures 7 and 8 show stems of lamps exhibiting the effects of currents of from one to 25 amperes passing through the wires and the vacuous space. The glass about the wires shows the fusing effect of the current, and the fracture of the glass shows the effect of the expansion of the wires by the heating effect of the current. The undisturbed condition of the glass between the two leading-in wires shows that the current did not pass across the glass, but must have passed through the vacuous space. Gradations of current from one to 25 amperes, used in this experiment, were obtained by regulating the amount of resistance in the circuit when the experiments were made. Unless some resistance had been left in the circuit, all of these lamps would have shown currents as high as 25 amperes or thereabouts, because the conductivity of the vacuous space increases very rapidly when the effect is great enough to start the fusion of the wires.

The lamp shown in Figure 9 illustrates the fact that the heat produced at the positive joints by the "Edison Effect" current is not simply the result of a mechanical bombardment. This lamp was exhausted to show a good blue. The temperature of the filament was raised sufficiently to cause vacuum currents large enough to heat the positive joint red hot. The outer end of the middle wire was then connected to the positive lamp terminal. When this was done the positive joint became cool and the middle wire got red hot. This was repeated several times. The middle wire got hot enough to fuse the end, which was platinum. This indicates that most of the heat is caused by the charged molecules coming in contact with some conductor which will carry away their charge. The current was not measured in this experiment.

Figure 10 shows the lamp used in a similar experiment. The middle wire carried a copper plate about 1″ long and ¼″ wide. This lamp was exhausted to show a good blue. An ammeter was connected between the middle wire and the positive lamp terminal. As the current was gradually raised, the vacuum current heated the copper plate until it was fused, as shown in the figure. The ammeter in this case indicated over five amperes flowing through the vacuous space between the negative leg of the filament and the copper plate.

I next tried a series of experiments to determine whether the current which passes through the vacuous space when the blue glow is present was the effect of charged molecules moving in straight lines only, from the negative leg, or whether this current would pass around a screen. If a blue glow should appear in lamps with a shield between the legs of the incandescent filament, it would be an indication that the charged molecules under these conditions could carry a current between the two legs in other than straight lines, and if the positive joint should get red hot in such a lamp it would indicate that the charged molecules pass around an obstacle quite freely. For this experiment I used a lamp with a glass plate 2¼″ long and ⅞″ wide between the legs of the incandescent filament. It was necessary to raise the filament in this lamp to a very high temperature before the blue appeared, and then instead of appearing gradually, as it does in ordinary lamps, it appeared suddenly and in great abundance and the positive joint got red hot, so that it was necessary to reduce the temperature of the filament to prevent the fusion of the joint wire. As the temperature was reduced, the blue gradually decreased, as it does in ordinary lamps.

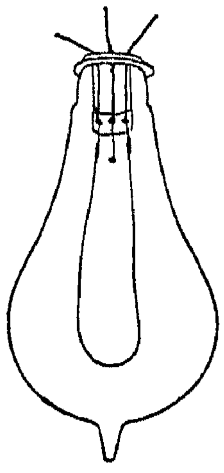
FIG. 9.

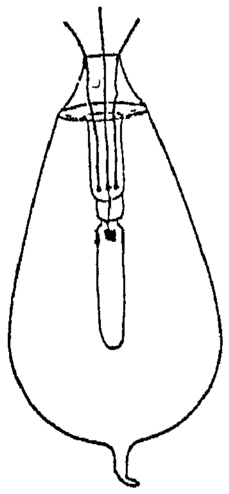
FIG. 10.

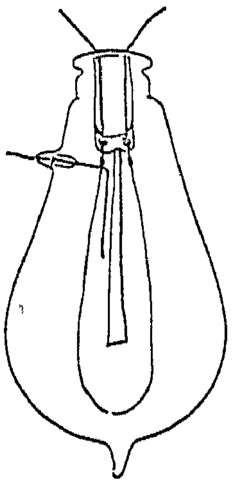
FIG. 11.

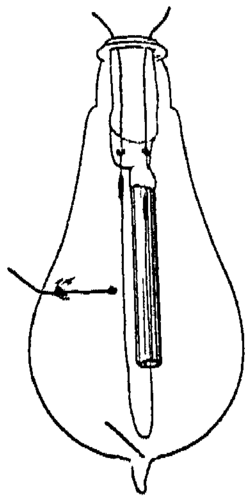
FIG. 12.

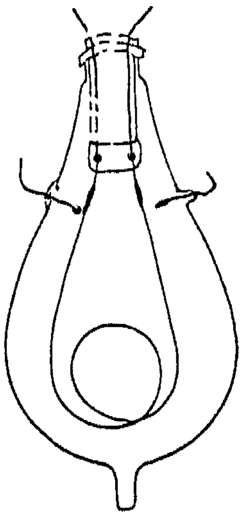
FIG. 13.

When the temperature was so reduced that very little blue was visible, the blue would increase gradually again if the temperature was increased. When the circuit was broken, the filament had to be again raised to the high temperature before the blue again appeared. In this lamp the blue appeared at 136 volts, and remained when the pressure was reduced to 109 volts, but would disappear between 109 and 101 volts.

My next experiment was with a lamp (shown in Fig. 11) having a platinum screen between the legs of the filament and a platinum wire sealed in the side of the bulb and projecting in the vacuous space, with its end bent so as to run parallel with one leg of the filament for about 1″ between the filament and the platinum plate. When this filament was heated to about a 2½-watts-per-candle temperature, the vacuum current did not pass around the screen and no blue showed in the vacuous space. That leg of the filament being negative which was on the same side of the screen as the wire which was sealed into the bulb, I connected the galvanometer between this wire and the positive lamp terminal. The galvanometer showed a strong current. On breaking the galvanometer circuit, blue appeared on the positive joint and in the bulb. I repeated this several times. It occurred when the temperature was considerably below the temperature necessary to start the blue around the screen.

In each case, connecting the galvanometer between the wire and the positive terminal would cause blue to appear about the inserted wire and the negative leg, and breaking the galvanometer circuit would cause blue to appear on the positive joint, and in the vacuous space about the positive joint, and about the negative leg of the filament.

With this same lamp I observed that when the filament was at a temperature not sufficient to start the blue, if I touched the positive terminal with one finger, and the inserted wire with the other, the blue immediately appeared in the vacuous space about the positive joint and the negative leg of the filament.

These experiments demonstrate that in lamps exhausted so as to show a good blue, the charged molecules have some difficulty in starting their passage from one leg to another around an obstacle, but maintain their passage after it has been once established. Also, that their passage around an obstacle is easily established by starting a flow of charged molecules from the negative leg through a small unobstructed part of the vacuous space, to an inserted wire which is connected to the positive terminal, and then breaking the positive terminal connection.

To determine how large a current could be made to flow around an obstruction in lamps exhausted to show a good blue, I used a lamp shown in Fig. 12, having a glass tube about the negative leg, and the wire sealed in the side of the bulb, running parallel with the positive leg for about 1″. I connected an ammeter between the inserted wire and the positive lamp terminal, and raised the temperature of the filament until a dense blue appeared in the vacuous space, and about the wire and the end of the glass tube. The temperature of the filament was raised until the vacuum current fused the platinum wire which was sealed into the bulb. When this occured, the ammeter indicated 2¼ amperes, and remained at this reading one or two seconds.

Any of the lamps in which the condition of the vacuum is just right, showing the blue glow, will show a current in a galvanometer connected between the wire inserted in the vacuous space, and the *negative* lamp terminal, but in all cases this current is small. One-half milliampere is the largest current I have observed under these conditions.

I next tried some experiments with lamps like the one shown in Fig. 13, which has two wires sealed in opposite sides of the bulb, which project inward to a point near the filament about ¼″ above the joints. This lamp was exhausted to show a good blue. The galvanometer was connected between the wires which were sealed in opposite points of the bulb. No current was indicated until the temperature of the filament was raised quite high, and the blue glow was quite intense.

Under these conditions the galvanometer indicated a current of .1 milliampere.

I have made experiments upon two lamps containing bromine vapor. One of these lamps which contained bromine enough to depress the barometric column $\frac{1}{20}$″, showed no "Edison Effect" when the potential was run up as high as 170 volts, using a 110-volt lamp.

The second lamp had very much less bromine vapor in it, and showed a very slight "Edison Effect." This lamp acted very peculiarly. When first tried it gave an "Edison Effect" which changed very little in value between 105 and 146 volts. At 120 volts, the vacuum current showed a deflection of the galvanometer of 14 scale divisions, while at 128 volts it showed a deflection of only 12 scale divisions. I observed this several times. This was quite a large reverse change, as the current at 146 volts only increased enough to give a deflection of the galvanometer of 16 scale divisions. This change was observed on several days, but it was less marked each time it was tried, until it finally disappeared.

The question naturally arises, what causes the blue glow in the vacuous space? The glow is luminous, and luminosity can only come from matter; consequently we conclude that the vacuous space, when blue shows, is filled with luminous molecules, and as these molecules are not of themselves luminous, we must seek for the cause of their luminosity.

We have seen that the negatively charged molecules liberate considerable energy on coming in contact with a body that conveys away their charge. We have also seen that when the blue glow is present there is a considerable flow of charged molecules through the vacuous space, and that the naturally rectilineal movements of these molecules are disturbed.

We also know that molecules are emitted from the positive leg about as plentifully as from the negative leg, although these molecules do not carry a positive charge.

The conclusion seems to be that the blue glow is a manifestation of the energy developed by the meeting of the charged molecules with other molecules which take away part or all of their charge.

Well exhausted incandescent lamps which have burned a long time show a black deposit on the inner surface of the bulb. In lamps with thick, stiff, single-loop filaments, in which the two legs lie in the same plane, a light line may be observed in the black deposit, which is caused by the shielding of this line by one leg, from the molecules emitted by the other leg. This line shows with about equal clearness opposite both legs, indicating that carbon molecules are constantly emitted from both legs, equally and in straight lines.

In lamps which have been imperfectly exhausted, the black deposit sometimes appears in patches, symmetrically placed with reference to the carbon. I regard these figured discolorations as indications of disturbances in the rectilineal paths of the molecules, and of the influence of the magnetic field upon the disturbed molecules.

The activity of the molecules carrying current across the vacuous space seems to depend more on the temperature of the filament than on the potential difference between the legs, 40-volt lamps showing about as strong effects as 140-volt lamps. The energy they exhibit in one direction seems to be very much greater than we would expect from molecules actuated by a potential difference of only 40 or 50 volts. The action of these molecules in carrying electricity in one direction only, may be an indication of the nature of the action between molecules in solid conductors carrying currents, rather than an illustration of the action of statically charged molecules.

DISCUSSION.

MR. JOHN W. HOWELL:—After I had written this paper, I broke the lamp having the graphite filament and took a part of the filament out, and measured its specific resistance. Its specific resistance (the resistance of a piece one inch long and one circular mil area) was 450 ohms. The lowest specific resistance I have ever measured of amorphous carbon is about 2200 ohms. The treatment obtained by hydrocarbon deposit is about 350 ohms, which is about six or seven times as low; and this graphite lamp was 450 ohms, which was very nearly the figure of the carbon obtained by treatment, and I think if it had been a more solid graphite it would have been lower. I can also say that the specific gravity of graphite is practically the same as the specific gravity of the carbon obtained by hydrocarbon deposit.

THE PRESIDENT:—How was that filament made?

MR. HOWELL:—It was simply made by making a die, filling it with graphite and solidifying it under great pressure—so great pressure that it made a solid graphite filament of it.

DR. A. E. KENNELLY:—I believe that I voice the general sentiment in saying that this is a very interesting paper, both by reason of what it contains of investigation and by reason of what it suggests for further inquiry.

I remember having taken part in the measurements of resistance in the lamp filament referred to. I believe that the theory given in this paper was suggested at that time for the apparently abnormal behavior of its resistances, but the additional evidence was not then forthcoming which enables Mr. Howell to make so strong a case for that theory in this paper.

It is perhaps no more surprising that graphite should differ markedly from ordinary carbon in its temperature co-efficient of resistivity, than that diamond should differ markedly from ordinary carbon in its hardness.

Incidentally it is curious to observe from the curves in the paper that approximately five per cent. of the voltage needed to produce an inefficiency of three watts per candle, raised the temperature of the filaments experimented on to 500° F., or 260° C.

It has long been known that the passage of a continuous current through a Geissler tube set up a series of pulsatory currents or discharges, which are capable of producing alternating currents in a separate circuit, through the intermediary of an alternating current transformer. So far as I know, however, it has been pointed out for the first time in this paper, that an alternating current passed through an incandescent lamp giving the "Edison Effect" is capable of producing in a branch circuit through a third wire in a lamp, continuous or at least undirectional currents. Consequently it is interesting to observe that a vacuum tube, in the broadest sense of the term, is capable of supplying not only alternating currents from continuous currents, but also continuous currents from alternating currents.

As regards the results obtained in the interesting manner described, it would appear that some of these observations differ from those quoted as obtained by Dr. Fleming. It would seem that Dr. Fleming took the position that the blue discharge can only travel in straight lines, whereas in some of the experiments here referred to, as, for example, those in connection with Figs. 11 and 12, the blue discharge and the "Edison Effect" did apparently go around a corner, and a sharp corner too.

I am unable to follow the conclusion mentioned by Mr. Howell, that the change in the development of heat from the positive joint to the middle wire, when the connections are changed, indicates that no bombardment can take place. It seems to me possible that bombardment might still take place under a directive influence determined by the point of connection. No doubt Mr. Howell can make this matter clear.

Mr. E. A. Colby:—I am deeply interested in Mr. Howell's paper, especially the latter part of it, referring to the so called "Edison Effect." While I am not prepared to-night to present any theory as to the phenomena observed, I can say that the characteristics which Mr. Howell has mentioned are well known to me. I would like to ask if he has substituted for the galvanometer which he used in measuring the currents, the still more sensitive instrument, the telephone, and whether he has attempted with its aid to explore the vacuous space by the insertion of platinum wires at different points in the glass bulb. Some years ago I tried an experiment of this character which was described in a discussion before the Institute. I sealed into a lamp bulb in the plane of the filament a number of platinum wires about one inch apart. Connecting the terminals of the telephone with the positive leg of the lamp, and with one of these wires I observed a note in the telephone which varied in pitch according to the position of the wire sealed into the bulb. When the telephone was connected to the positive leg on one side, and to the platinum terminal which was nearly at the middle of the filament, or more correctly on the diagonal to positive terminal of the area enclosed by the legs of the filament, I obtained the maximum note, and as I carried this terminal of the telephone near to the negative leg of the filament I got practically no sound whatever. I also inserted in a similar lamp a glass plate, upon which I obtained a deposit of carbon upon one side only, the depth of the deposit apparently increasing from the base of the lamp to the apex, indicating that particles of carbon were actually transferred from one leg of the filament to this glass plate. I then attempted to produce mechanical motion within the bulb of the lamp by constructing a very delicate mill out of mica vanes, and supporting the same between the legs of the filament. This mill was composed of four aluminium arms with mica vanes attached, and was shaded—half of it—so that only one portion would be exposed to the impact of the carbon molecules. This experiment was only tried once and proved a failure.

I notice that Mr. Howell reaches the conclusion that the luminosity is due to the energy set free by the impact of the molecules of matter present, which is undoubtedly the case. I should be very glad if he would express an opinion as to what may be the nature of these molecules, whether they are particles of carbon, or whether they are hydrogen gas, or compounds of hydrogen with carbon.

There is one other point which I would like to bring up, and that is the effect of gases, such as bromine, left in the bulb. I entirely agree with Mr. Howell that when bromine gas in an appreciable amount is left in a bulb, the blue discharge disappears, and that the current across the vacuous space is absent. I have also found the same to be true if the vacuous space or the space within the lamp bulb is occupied by the vapor of chloroform and various other hydrocarbons. But I have also noticed that when certain compounds are present in the bulb, the blue discharge, instead of disappearing, actually increases. And notably I recall a case where a lamp had been exhausted which had attached to the bulb a tube containing mercuric cyanide. Upon heating this tube until the glass was ready to collapse we forced the vapor of mercuric cyanide, or possibly the components of mercuric cyanide, into the lamp bulb. Upon raising the current appreciably afterwards, the blue discharge suddenly appeared and spread out in concentric rings from the positive leg nearly reaching to the negative, and a short circuit resulted after the lamp had remained on the pump a few moments. The same increase in the blue discharge I had also observed in lamps containing filaments which were imperfectly carbonized. In the earlier manufacture of the tamadine filament we undertook to carbonize the material, utilizing the same temperature with which we had been carbonizing the ordinary paper and silk filaments, but unfortunately we were unable to reach a temperature high enough to effect complete decomposition of the tamadine. Filaments made in this way, upon being sealed in the lamp bulbs and having a current passed through them, became further carbonized, and the result was, that a large amount of gas was liberated and the globes were filled completely with a violet blue discharge, and if the current was allowed to continue, short circuits inevitably resulted. This indicated to me at the time, that the blue discharge was possibly due to the presence of gases which were liberated from the carbon filaments, and that the blue discharge in other lamps which appears when a high degree of exhaustion is reached, appearing as it does at the stubs or the points at the lowest temperature, possibly was due to the presence of occluded gases at those points, which in working their way out gave rise to the blue discharge. To investigate this matter further, I remember that we sealed glass tubes to the platinum wires so that the tubes surrounded the stubs. Upon raising the current to the point at which the blue discharge usually appeared we failed to obtain it. But upon raising it still more, suddenly the blue discharge shot out from the glass tube surrounding the positive leg in a large amount, and the temperature at that point was so high that the glass tube was fused. I have noticed also the same effect which Mr. Howell mentions of the heating of the platinum wire on the positive side due to the vacuum current. I have succeeded more than once in obtaining this effect without fusing the platinum wire; raising the wire to a red heat throughout its seal from the interior to the outside, and upon reversing the current obtaining the same effect upon the opposite side. The blue discharge first appearing at the stub and gradually traveling down the wire, I thought at the time that it might be due to gases occluded in the platinum wire itself. You are all familiar with the fact that there is a process of electric forging in which the metal is connected to the negative pole and inserted into a liquid bath, and upon turning on a sufficient amount of current the negative electrode becomes heated to a very high temperature. I believe the theory for this is that the metal becomes enclosed in an atmosphere of hydrogen, the resistance of contact being so high that the temperature is raised to a white heat. It occurred to me that platinum, occluding as it does so much hydrogen, and possibly, also the stubs and filaments, which at very high temperatures may be giving off hydrogen as a result of further decomposition, might account for the appearance of this blue discharge. I am exceedingly grateful, personally, to Mr. Howell for his lucid explanation of the phenomena.

Dr. Samuel Sheldon:—Last year, when Röntgen first gave out his results, I was looking through the literature of the subject of Crookes tubes, and I came across one piece of information which struck me as rather peculiar and which may bear upon this subject here. It was that a Crookes tube with two electrodes constituted a condenser; that the capacity of this condenser depended upon the condition of the exhaustion, upon the size of the electrodes and upon the distance between the electrodes; that the dielectric of this condenser, if it can be so called, exhibited the peculiar property of breaking down when the voltage impressed upon the electrodes exceeded a certain amount, and that when a Crookes tube was properly operated so as to glow, that the voltage upon the terminals was always of a definite amount; it never exceeded that amount, for if an electromotive force which was greater than the amount necessary to produce this glow discharge should be impressed upon the two electrodes, the difference of potential was reduced by an adjustment between the internal resistance of the coil or source of electromotive force and a series of pulsatory discharges of widely varying frequency between the two electrodes. I speak of this in this connection because it seems to me perhaps to explain the experiment of Mr. Howell represented in Figure 11, where the discharge was not observed between the negative terminal and the positive terminal when a shield was interposed, but which was started at the moment that the intermediate wire was connected with the negative terminal. In the latter case, the length of path between the interposed wire and the positive terminal was lessened to such an extent that perhaps, possibly, the voltage which was impressed on the two terminals and which was in this case limited, because it was short-circuited through the filament, was enabled to give a discharge, and that once having been started the character of the discharge was maintained, as is often the case in a Crookes tube.

Mr. Colby:—I would like to ask Mr. Howell if he has made any examination of the blue discharge by means of the spectroscope. I have in my notes, under October 11th, 1883, an instance where we had this pronounced blue discharge. Upon examination of the discharge with the spectroscope, a number of very bright lines to the right of the D or sodium line were seen. But unfortunately, before their position could be fixed the lamp short-circuited. In every case I find my notes indicate the presence of the same lines. I have here a small diagram of the spectrum, indicating as nearly as could be done by three observers, Mr. Weston, Professor Garver and myself, where these lines were located. The sodium line was clearly visible. The most marked line was a bright green, which Mr. Weston thought was possibly due to the presence of mercury. It might possibly have been mistaken for hydrogen. Hydrogen and oxygen would undoubtedly be present from the decomposition taking place. Mr. Weston's theory is—I am reading notes which were made at that date—that the presence of hydrogen brings out the mercury lines. The exhaustion in all these cases is incomplete. I think it would be very interesting, if Mr. Howell has the facilities, to study the blue discharge by means of the spectroscope. Possibly we can thus get information as to what matter is present, giving rise to the discharge.

Secretary Pope (in the chair):—The questions involved in this very interesting paper are necessarily confined to the observations of those who are engaged in a special branch of the business, and for a moment, when Mr. Colby spoke of the date of his notes, I paused to think whether we had incandescent lamps in 1883. I think it would be of interest, when Mr. Howell rises to close the discussion, if he would intimate what bearing this investigation has upon the manufacture of lamps, or possibly its interest to users of them. How these lamps are made, and the intricate processes they go through in treating these filaments, is of course a sealed book to many. If there are any gentlemen present who are not members of the INSTITUTE, they are at liberty to make any remarks or ask any questions of the author.

MR. DOUGLASS BURNETT:—I have a request to make of Mr. Howell, that in closing his remarks he will tell some of the younger members what tamadine is.

MR. COLBY:—Tamadine is a name which unfortunately conveys very little meaning. It is a name which was compounded by one of Mr. Weston's assistants—his secretary, I believe—who had a more familiar acquaintance with the Greek language, or more time to hunt up Greek words which would convey the true meaning of what was intended than the rest of us. Tamadine is simply a cellulose filament which is made by dissolving ordinary gun-cotton in a mixture of ether and alcohol; pouring the solution on a glass plate, the solvents evaporate, leaving what is generally known as collodion. Of course in this state it is highly inflammable, and it must be treated chemically to remove the oxygen combined with it before it can be carbonized. The advantages claimed for it were that it gave a homogeneous filament. [The literal meaning of tamadine being "without structure.]" Now that I am up—I am sorry to take so much time, but these notes I have not looked over for a good many years—I find on December 26, 1883, that I made a lamp in the shape of a U tube for the purpose of investigating still further this blue discharge. It was a lamp with a large filament, 125 C. P. lamp, and a straight tube was made of sufficient length to contain this filament, and then bent up in the shape of the letter U. In this way a most effective screen was interposed between the positive and negative legs. I exhausted this lamp as finely as possible, increasing the current until both stubs were very hot, without noting the least trace of discharge. After burning at high candle power for several hours, the carbon was perfectly clean. In other words, there was no discoloration of the negative leg, as is often observed, but the sides of the tube were badly blackened. The mechanical difficulties of making a lamp of this character were too great, of course, to adapt it to commercial purposes.

MR. WOLCOTT:—In connection with the explanation of what tamadine is, I will say it is entirely new to me that tamadine is nitro-cellulose, or celluloid, as you may say. I certainly read in the electrical journals once that it was made by treating cellulose proper with ammonium sulphide. Some one wrote an article saying that that was what it was.

Mr. Colby:—It was made as I described a moment ago, in the laboratory. To turn it out in large quantities, of course that process was altogether too slow, and we resorted to the facilities of the Celluloid Manufacturing Company of Newark, and they made it by treating ordinary tissue paper and reducing it to the chemical state such that it became soluble in a mixture of ether and alcohol with certain other compounds.

Mr. Wolcott:—They made nitro-cellulose of it.

Mr. Colby:—Practically. I cannot speak with knowledge of their process or the exact chemical composition, because that is a secret they keep themselves.

Mr. Wolcott:—Some one wrote an article—I forget who it was—stating that Mr. Weston had discovered a process of forming this material by treating the cellulose or paper with ammonium sulphide, and that is entirely different. Of course I do not know whether there is anything in that or not.

Mr. Colby:—That is something I never heard of. The only use to which we put ammonium sulphide was to reduce the nitro-cellulose. It was treated with that to render it less inflammable. Very likely that is the origin of the statement.

Mr. Charles Wirt:—I have never seen a statement of the fact that contact resistance between metals has a negative temperature co-efficient. This is a fact which I found out by experiments some years ago, and I have always associated this peculiarity with the negative temperature co-efficient carbon, which being (at least in most forms) of rather loose structure and of high resistance, is rather suggestive of contact resistance between particles. The reversal of this temperature curve in Mr. Howell's diagram interests me very much, and I would like to know more about it. It looks as if that sample of graphite, after passing a certain temperature, became something that was not graphite. We get a striking change in the nature of phosphorus by simple heating of the material, the resulting allotropic form being decidedly unlike the original. If Mr. Kennelly or Mr. Howell, or somebody else, would investigate this graphite further, perhaps we may learn how to make diamonds.

Mr. Howell:—Mr. Kennelly suggests that the argument which I made that the heating effect observed on the positive joint, or on a positively connected inserted wire, was not due to molecular bombardment was not conclusive. The lamp shown in Figure 10 had a copper plate an inch long and about a quarter of an inch wide between the legs of the filament, and the filament itself was only one and one-half inches high, so that the little globule which you see in Figure 10 at the end of the wire is the result of the melting of a copper plate which extended two-thirds at least of the length of the loop. In that lamp there was no indication of heat on that copper plate, unless this external wire was connected with the positive terminal. The plate would naturally receive a very large proportion of the molecular bombardment, which was directly across, between the two legs. It shielded the positive joint of the lamp from a large part of the direct molecular bombardment, and yet it would not get hot, and the positive joint would get hot; but just as soon as that middle plate was connected to the positive wire, then that plate got hot and the joint got cold. I think that is quite conclusive that the bombardment itself does not produce very much heat. It may produce some, but not very much until there is positive connection made which allows the molecules to discharge to a point of high potential.

Mr. Kennelly also suggests that my conclusions are somewhat in conflict with those of Professor Fleming. They are not. Professor Fleming's work was all done with lamps which were highly exhausted. All the highly exhausted lamps with which I experimented behaved exactly as Prof. Fleming's did. There was every indication that the molecules passed in straight lines only. They would not pass around the screen shown in Fig. 11, and their effects would not be exhibited in the lamp shown in Fig. 12 when the negative leg was in the tube. The power to pass in other than straight lines exists only, so far as my experience shows, when the vacuum is in a condition to give a blue glow. In that case I believe that there is a large number of molecular collisions constantly occurring in the vacuous space, and perhaps the charged molecules do not go from the negative to the positive around corners, but go to other molecules to which they give up their charge. Probably the motion is in a number of straight lines instead of one. But in all cases in which the lamp had a high vacuum, as it was in all the lamps Prof. Fleming used, I found no ability to pass in other than straight lines.

Mr. Colby speaks of substituting for the galvanometer a telephone for exploring the potentials of the vacuous space. That point was very thoroughly covered by Professor Fleming, with a condenser, which is still better than a telephone. The indications of the telephone are not simply indications of potential, but are indications of current, and the current in this case must depend on the number of molecules which are received by the positively connected wire. His experiments with a telephone are entirely in accord with all of my experience, which shows the current a maximum between the positive terminal and a point near the bottom of the negative leg of the filament, and that as you go distant from the foot of the negative leg you get less and less total bombardment for given surface, and less effect on the telephone. But with the condenser you find the potential is the same everywhere; anywhere in the vacuous space in which you insert a wire and get its potential difference between the positive electrode and that point. In fact, every point of the vacuum is reduced to the potential of the negative leg. The condenser was allowed to charge, and was discharged through a ballistic galvanometer.

Mr. Colby's question as to whether the luminosity was due to the energy of carbon or of other molecules, I do not know that I can answer fully; but I think there is every indication that it is due not to carbon molecules but to others. I do not think it is possible to get a blue glow in a lamp after it has been well exhausted—after it has been exhausted of everything except the carbon molecules which come from the filament. It is only to be obtained when there is some other gas or vapor in the lamp. Water vapor causes a very marked blue effect. One fact which I mentioned in this paper was that in the presence of a blue discharge, if a direct current is used in heating the filament, a black deposit will appear on the negative leg, and yet you know that the bombardment which affects the galvanometer is from the negative leg. Yet the black appeared on the negative leg, showing that there is a transfer of carbon molecules, probably from the gas in the bulb, to the negative leg, and that is always observed where you have a blue glow, but you can never observe that in a well exhausted lamp. When a filament is heated with a direct current the carbon molecules proceed from both legs equally. I do not think there is any evidence in my possession which indicates that there is a greater throwing off of carbon molecules from one leg than from the other. I know that other observers have stated that there was such evidence, and that the carbon molecules were thrown off very freely from the negative leg. There is no evidence which I have which supports it. There is plenty of evidence that if one leg of the carbon is a little thinner than the other, and hotter, it will throw off a good deal more carbon at its higher temperature. But the great number of lamps which I have seen which show an equal shade on both sides of the bulb indicate that that is equal from both legs when both are equally hot.

Mr. Wirt's suggestion as to the investigation of graphite of high temperatures and the possibility of its changing into something which is not graphite is worthy of consideration. But the fact immediately presents itself that when the carbon is cold it is graphite again. It is pretty hard to investigate a white hot substance which has the power to go back to its old condition when it gets cool again.

Mr. Pope speaks of the bearing which this paper has on the manufacture of lamps. The only bearing it has is to tell us not to make lamps that show blue.

The action of these molecules emanating effectively from the negative leg only, is very curious, and I hoped that the suggestion which I made at the very end of this paper would be taken up and discussed by somebody who knew more about it than I did; that is, that the action of these molecules in carrying electricity in one direction only, may be an indication of the nature of the action between molecules in solid conductors, carrying conductors, rather than an illustration of the action of statically charged molecules. I think there is evidence that the action of these molecules has very little to do with their static charge. We know that in order to produce effects by a static charge in an ordinary vacuum you have got to use very high potentials and quite a large amount of actual energy. Whereas in these cases, a lamp which requires a very low potential difference will give a very strong molecular effect, and its passage in one way only is rather hard to explain. In fact, Prof. Fleming does not explain it He says it is so because it is so, practically, and I am sure I cannot explain it. But it is a fact that the current is carried in one direction through the vacuum just as it would be if it were a conductor with all its resistance at the positive contact. If this were so, an inserted wire would show the same effects as those we observe in actual lamps. We have measured currents as high as 25 amperes passing through a space in which there is no continuous matter—that is, matter in the continuous condition we think of when we speak of a solid. When that current is passing, there is a vacuum there which is so high that it would scarcely depress a barometric column. In fact, I tried to measure whether there was a depression of a mercury column, and if there is any it is very slight indeed. Under proper conditions, a vacuum which will not appreciably depress a mercury column will carry a current and appear to have practically no resistance except at the positive contact. The vacuum will sometimes change from an insulator to an almost perfect conductor suddenly, without any gradations at all. It will be a sudden change due only to a suddenly acquired ability of the molecules to carry the current across the space in one direction only. The indication of the unidirectional current from the alternating current is very interesting. It was a natural result, and it was one which I predicted before I tried it. I made an indicator for an alternating circuit in that way by using a lamp with a third wire which had a high degree of exhaustion on an alternating circuit, the alternating circuit giving the carbon its temperature, and the variations in the current affected an ordinary direct current galvanometer connected between the inserted wire and one electrode, and it seemed very strange to see an undirectional current taken out of an alternating current in this way.

On motion of Mr. Kennelly a vote of thanks was tendered to Mr. Howell for his very interesting paper.

[Adjourned.]

[COMMUNICATED AFTER ADJOURNMENT BY PROF. W. M. STINE]

PROF. W. M. STINE:—Perhaps the most elaborate investigations of the "Edison Effect" have been carried out by Professor J. A. Fleming. In a lecture before the Royal Institution, in 1890,[1] he developed about all the leading facts which he has since elaborated.[2] His experiments, together with those detailed in the paper under discussion, reveal a large number of facts, interesting alike to the student of physics and the manufacturer and user of the incandescent lamp.

In Professor Anthony's paper before the INSTITUTE in 1894, it was stated that carbon was removed from the filament through the action of convection currents. This was taken exception to at the time, and the evidence from experiments on the "Edison Effect" clearly disprove this assumption. In one of the lamps employed by Professor Fleming, containing a sealed-in aluminium plate, this accidentally vaporized, coating the walls with metallic aluminium, and leaving a well-defined molecular shadow of the filament. It may then be held that in the high vacuum of an incandescent lamp, metals or carbon brought to incandescence truly vaporize, and the molecules leave the surface and travel in straight lines, having a fairly free molecular path. Nor can the driving off of carbon molecules from the filament be regarded as an electrical act; it is rather due to evaporation at high temperature, and can be assisted by electrical repulsion but to a limited extent, since the voltage in lamp filaments is usually very low. This is confirmed by the present paper. Mr. Howell found the "Edison Effect" to be as strong between the filament legs of a 40-volt lamp as one operated at 140 volts, it being assumed that the temperature of incandescence was the same in each case. In a curve given by Professor Fleming, the "Edison Effect" is approximately a linear function of the volts between the lamp terminals. The temperature of the filaments in such a case is itself almost a linear function of the volts. His curve actually bends slightly downwards,[3] showing the influence of increased heat losses by radiation. Had the evaporation been influenced by the highest voltage to any appreciable extent, the curve must have bent *upwards*. Again, were the discharge of the molecules due to their static charges, the "Edison effect" would occur in a filament of uniform cross-section about equally over the entire surface. Another noteworthy experiment of Fleming was to seal similar filaments in the end of an egg-shaped tube. These were heated to incandescence by battery currents. A single cell of battery connected to points on the two filaments, which were at equal potentials, was able to send a marked current through the tube. This experiment establishes two facts: that incandescent carbon fills a vacuum tube with a carbon atmosphere of high conducting power, and that this vapor conducts an electrical current much as does a solid conductor.

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[1] Reprinted in *Scientific American Supplement*, August 23, 1890.
[2] *Phil. Mag.*, July, 1896.
[3] *Phil. Mag.*, July, 1896, p. 57.

Perhaps the most singular phenomenon in this connection is the unilateral nature of electrical discharge from an incandescent source. The carbon vapor itself conducts equally well in any direction, but the discharge takes place only from the negative side of the filament. This, again, is another proof that the "Edison Effect" is not a static one, since the entire filament would be covered with a static discharge of the same sign. Guthrie long since showed that an incandescent conductor would discharge negative but not positive electricity. The action of the Crookes tube with cold electrodes is, in the main, of a similar nature. These facts indicate, as Lord Kelvin pointed out some years since, that there is a radical difference in character between positive and negative charges. It is probable that we shall yet find in such facts as these the explanation of the nature of electrical conduction.

A very significant statement is made on page 39 of the present paper, in connection with the sudden appearance of the blue glow in the lamp. The same thing is frequently seen in Röntgen tubes. With a very high vacuum scarcely any current passes. If the tube is heated, the vacuum is lowered gradually until a critical point is reached. At this point a blue glow suddenly appears about the anode, and the resistance of the tube very materially decreases, with an equal suddenness. At this point the atmosphere seems to cease carrying the current by moving electrical charges, and becomes, in a sense, a true conductor.

Another interesting effect is, the larger the conducting plate sealed into the bulb, the greater the flow of current. The subject is one of great practical importance. It clearly points out the value of high exhaustion for lamps. That a lamp containing an atmosphere of a heavy, non-conducting gas, such as bromine, exhibits these effects but feebly, is also significant. High efficiency lamps, even with excellent vacuum, ought not to be pushed to a high filament temperature, or they become to a certain extent short-circuited. This indicates an unfortunate limit to the increase of the efficiency of carbon filaments. It is probable that though the "Edison Effect" may be decreased, it can never be wholly avoided, since a carbon burned in the air will exhibit the effect while it lasts. Lamps containing heavy non-conducting gases in their bulbs, as Professor Anthony has shown, do not blacken to any extent. The present paper shows how small the "Edison Effect" is in them.

OBITUARY.

Ezra Carl Breithaupt (Associate Member June 6th, 1893; Member, May 19th, 1896), fourth son of the late Louis Breithaupt, was born in Berlin, Ontario, on February 19th, 1866, and there he received his early education. He attended the Northwestern College, at Naperville, Ill., and graduated from it in 1887. He travelled for some time, and then went to Johns Hopkins University, at Baltimore, to take the course in electricity. In 1892 he graduated from Johns Hopkins with the degree of "Electrical Engineer," and, on returning to Berlin, he became the Manager of the Berlin Gas and Electric Company, which position he held up to the time of his death.

As consulting and electrical engineer, he had a general practice in Ontario and Quebec, and as such he acted for the town of Bracebridge on the installation of a large lighting plant. He laid out. and superintended the work of electrically equipping the Berlin and Waterloo Street Railway, and later became its president and manager. He also acted as consulting engineer for the town of Sherbrooke, Quebec, for the Penetanguishene and Midland Electrical Railway Company, and for various other enterprises.

He was a member of the Canadian Electrical Association since its inception, and was a most active and valuable member of its executive and statistics committees, of which latter he was chairman. In June last he was elected to the office of second vice-president of the association. During his connection with the association he prepared and presented to it several valuable papers, and he also contributed papers to various electrical publications, principally dealing with Canadian developments in electrical engineering.

He was a member of the Berlin Board of Trade and of the Toronto Board of Trade, and at one time was president of the former.

Mr. Breithaupt's death, on January 27th, 1897, resulting from injuries received at an explosion of an oil tank at the Berlin gas works, is particularly sad, as it came at what was only the beginning of a career of great promise. He leaves a large circle of relatives and friends to whom his affability, his manliness and his conscientiousness had endeared him.

THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, March 24, 1897.

The 114th meeting of the INSTITUTE was held this date at 12 West 31st Street, and was called to order by President Duncan at 8.30 P. M.

PRESIDENT DUNCAN:—The Secretary will announce the ticket nominated by the Council at the meeting this afternoon.

THE SECRETARY:—From the nomination returns received from the membership, the Council has selected the following names which will be printed on the ballots for the guidance of members in their choice of candidates.

For President:
FRANCIS B. CROCKER, of New York City.

For Vice-Presidents:
A. E. KENNELLY, of Philadelphia, Pa.
CHAS. S. BRADLEY, of New York City.
DUGALD C. JACKSON, of Madison, Wis.

For Managers:
ALEXANDER MACFARLANE, of South Bethlehem, Pa.
GANO S. DUNN, of New York City.
W. F. C. HASSON, of San Francisco.
HERBERT LAWS WEBB, of New York City.

For Treasurer:
GEORGE A. HAMILTON, of New York City.

For Secretary:
RALPH W. POPE, of New York City.

The Council has decided to hold the General Meeting of the INSTITUTE at Greenacre-on-the-Piscataqua, Eliot, Maine, beginning on July 26th. This place was the residence of the late Moses G. Farmer, who was one of the charter members of the INSTITUTE and made an Honorary Member October 21st, 1890. He died at Chicago, May 25th, 1893, having been actively engaged in the preparation of his personal exhibit for the World's Fair. The date selected will be the 50th anniversary of Prof.

Farmer's relinquishment of teaching and the taking up of electrical work. Greenacre is beautifully situated on the east bank of the Piscataqua River, about ten miles beyond Portsmouth, N. H., and is reached in two hours from Boston.

The Annual Meeting for the election of officers, presentation of yearly reports, etc., will be held at 12 West 31st Street, as provided by the Constitution, on Tuesday, May 18th, which is the third Tuesday in the month.

The following Associate Members were elected at the meeting of the Executive Committee in the afternoon:

Name.	Address	Endorsed by.
Bechtel, Ernest J.	Superintendent, Power Plant, Toledo Traction Co., Toledo, O.	E. S. Reid. W. E. Harrington. R. W. Pope.
Ford, Arthur Hillyer,	Fellow in Electrical Engineering, University of Wisconsin, Madison, Wis.	J. E. Davies, D. C. Jackson. S. B. Fortenbaugh.
Holbrow, Herman L.	With New York Telephone Co., New York City, residence Rutherford, N. J.	S. B. Austin. H. F. Thurber. W. M. Petty.
Kelly, William F.	Student in Expert Course, Fort Wayne Electric Corporation, Fort Wayne, Ind.	F. S, Hunting. E. A. Barnes. A. L. Hadley.

Total 4.

The President:—The paper to be read this evening is on "The Influence of Heat Treatment Upon the Magnetic Properties of Steel and Iron," by Dr. K. E. Guthe. The paper will be presented by Professor Carhart, whom we all know.

Professor Carhart then read the following paper:

A paper presented at the 114th meeting of the American Institute of Electrical Engineers, New York, March 24th, 1897, President Duncan in the Chair.

THE INFLUENCE OF HEAT TREATMENT UPON THE MAGNETIC PROPERTIES OF STEEL AND IRON.

BY DR. K. E. GUTHE.

Steel and iron, when heated to high temperatures, show a decided change in their magnetic properties. The earlier investigations[1] have shown, that in general the temporary induction in iron and steel rods increases with increase of temperature. G. Wiedemann[2] found that very hard steel rods show at 100° a larger temporary magnetic moment than at 0°, soft rods a larger magnetic moment at 0° than at 100° for the same magnetizing force, after they had been repeatedly heated and cooled. Rowland[3] showed that a rise of temperature causes an increase of induction, if the magnetizing force is small, but a diminution of induction if the magnetizing force is large. The same was observed by J. Hopkinson,[4] who undertook a great number of experiments in this line, especially in order to show the relation between the critical temperature, at which iron ceases to be magnetic, and the recalescence, first discovered by Barrett. According to the former, recalescence occurs at the critical temperature. Osmond, who distinguishes three points of recalescence for soft steel, places the critical temperature at the second point of recalescence. Tomlinson's[5] and Kunz's[6] experiments show also the change in magnetic properties due to a rise of temperature.

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1. Wiedemann's "Electricitæt," 2d ed., III., p. 848–860.
2. G. Wiedemann. *Pogg. Ann.* 122, 346, 1864.
3. Rowland. *Phil. Mag.* (4), 48, 321, 1874.
4. Hopkinson, *Phil. Trans.*, 180 A, 442, 1889. *Proc. Roy. Soc.*, 48, 442, 1890.
5. Tomlinson. *Phil. Mag.* (5), 25, 372, 1888.
6, Program Gymnasium zu Darmstadt, 1893.

After steel has been heated beyond recalescence and is suddenly quenched in cold water, the mechanical hardening is accompanied by a corresponding magnetic hardening, *i. e.*, the permeability decreases and the hysteresis loss increases greatly. This influence of hardening is well known, and was first thoroughly investigated by Ewing.[1] Very little is known about the influence of heat treatment on such hardened steel. Barus and Strouhal,[2] in an exhaustive paper, show the influence of tempering on the retentivity of steel magnets, and are the originators of the well-known method of seasoning magnets by subjecting them for several hours to a temperature of 100°, which method has recently been used very successfully by B. O. Pierce. Their results, as far as they have a bearing on the present research, are, (1) that the magnetic moment of a hardened steel magnet is smaller after reheating to about 100° than it was before, and that on heating to still higher temperatures it increases again; (2) that the length of time during which the bars have been at the high temperature is of some influence, especially for the lower temperatures. The present work was undertaken with a view of following the annealing process step by step, and obtaining the relations between the magnetizing force, maximum induction, remanence and coercive force for each of these steps. The results are also interesting from a theoretical point of view, since they show a decided difference in the rate of change of the magnetic properties for the different temperatures.

Description of the Method.—The rings were all of the same form, *i. e*, hoops with an average diameter of 12.6 cm. and a thickness of only 8 mm. The diameters were measured by vernier calipers and the cross-section was found by dividing the volume, which was determined by the loss of weight in water, by the average circumference. New measurements were taken every time after the rings had been subjected to a temperature higher than 600°. They were wound with bicycle tape, and on this the primary coil. Before each experiment the insulation was carefully tested. Rowland's ballistic method was employed. Instead of the usual way of finding the constant of the galvanometer by means of an earth-coil, I charged and discharged a standard condenser through the galvanometer (see Carhart and

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[1] Ewing. *Phil. Trans.*, 547, 1885, or Ewing, "Magnetic Induction," etc., p. 82.

[2] "U. S. Geological Survey," No. 14, 1885.

Patterson's "Electrical Measurements"). The equations used will then be

$$\mathcal{B} = \frac{d_2\, C\, E\, r}{d_1\, n_2} \frac{100}{A}$$

where

$\mathcal{B}$ = the increase in induction,
d_2 = the deflection due to the change of the magnetic flux through one square centimetre of the ring,
C = the capacity of the standard condenser expressed in microfarads (= .2 microf.),
E = the *E. M. F.* of the Carhart-Clark cell in volts,
r = the total resistance of the secondary circuit,
d_1 = the deflection obtained by the discharge of the condenser,
n_2 = the number of secondary turns around the ring, which was equal to 30 in every case,
A = the cross-section of the ring,

and

$$\mathcal{H} = \frac{4\, \pi\, n_1}{10\, L}\, I$$

where

$\mathcal{H}$ = the magnetizing force,
n_1 = the number of primary turns on the ring,
I = the magnetizing current expressed in amperes,
L = the average circumference.

The deflection due to the discharge of the condenser was taken on open circuit. This produces an error in the constant. An independent experiment showed that the value obtained is 1.50 per cent. too large. In order to obtain the absolute values for $\mathcal{B}$ in the following tables, the data should be multiplied by .985. In order to eliminate the error due to the creeping up of the induction, the steps taken were as nearly as possible the same for the same ring at different stages of the treatment. I believe the total errors of observation to lie within .5 per cent. The experiments at each step for each ring consisted in the determination of the hysteresis curves for a number (8-10) of different magnetizing forces, the largest in every case being between 60 and 65. In the final results I give the hysteresis curves for the largest values of $\mathcal{H}$ only. The magnetizing curves were taken, but they are not given under the following results, since, as Hopkinson has shown, this curve for virgin steel differs appreciably from one taken with a ring previously magnetized. It was thought to be of more importance to represent the curves for $\mathcal{B}_m$ and $\mathcal{B}_r$ as functions of the maximum magnetizing force. (See Fig. 4.). Moreover, it was possible to show the influence of the reheating upon Houston and Kennelly's law,[1] *i. e.*, that for small magnetizing forces the remanence ($\mathcal{B}_r$) is a linear function of the maximum induction ($\mathcal{B}_m$). These two values, $\mathcal{B}_m$ and $\mathcal{B}_r$, are plotted on Fig. 5, and these curves are of great interest, showing the range through which this law holds good in the different stages of the heating process, and what variations in the constants are produced by the tempering.

Chemical Analysis.—the chemical analysis of the rings gave the following results:

	Ring I. Crescent Steel.	Ring II. Basic Steel.	Ring III. Very Soft Steel.	Ring IV. Swedish Iron.
Carbon	.868%	.309%	.0755%	.144%
Silicon............	.234	.025	.0155	.0624
Sulphur	trace	.059	.0645	.015
Phosphorus.......	.0172	.146	.124	.018
Manganese.	.27	.78	.36	trace

For the chemical analysis and the heat treatment of the rings, I am greatly indebted to Prof. E. D. Campbell, director of the metallurgical laboratory, and his assistant, Mr. A. R. Miller. I gladly express my deep obligations to them, especially to Professor Campbell, who devised and superintended every particular of the complete heat treatment.

The rings were first heated in the original state and then subjected to the heat treatment. The different steps taken are the following:

A. Rings in the original state.

B. Heated to about 670° and quenched.

C. Heated to a little over 900° and quenched.

The hardened rings were then tempered by reheating to the temperatures indicated below, and then allowed to cool slowly. D, 100° for one hour; E and F, 100° for 24 hours; G, 200°; H, 300°; I, 450°; K, 800°; L (only for Rings II. and III.), about 950°.

RESULTS.

In the following tables n_1 designates the number of primary turns, *c* the deflection of the galvanometer, obtained by the discharge of a capacity equal to .2 microfarad charged by a Carhart-Clark standard cell, *d* the deflection of the galvanometer due to the change of the lines of magnetic force in the ring, $\mathcal{B}$ the calculated value of the induction, I the current in the primary measured in amperes, $\mathcal{H}$ the value of the magnetizing force.

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[1] *Electrical World*, 25, 631, 1895.

It will be noticed that I give only the values of $\mathcal{B}$ and $\mathcal{H}$ for one side of the hysteresis curves. Since the same steps were taken on the ascending and descending branch of the loop, the values were generally identical, and are therefore not recorded in the following tables, though the whole cycle was taken in the actual experiments:

A. BEFORE HEATING.

TABLE I.

RING I; $n_1 = 298$: const. = 141.5; $\mathcal{B} = 18.7 \times d$; $\mathcal{H} = 9.45\ I$.			
d	$\mathcal{B}$	I	$\mathcal{H}$
—	+7966	0	0
48	7096	.270	2.55
14	6807	.350	3.31
47	5928	.538	5.09
64	4731	.705	6.67
184	1290	.940	8.89
197	−2394	1.210	11.44
192	5984	1.7	16.07
88	7630	2.09	19.76
87	9257	2.66	25.15
107	11257	3.86	36.50
63	12436	4.9	46.33
75	13838	6 5	61 46
47	12959	4.1	38.76
69	11669	2.1	19.86
88	10023	.86	8.13
110	7966	0	0

TABLE II.

RING II; $n_1 = 292$: const. = 141.5; $\mathcal{B} = 22.2 \times d$; $\mathcal{H} = 9.39\ I$			
d	$\mathcal{B}$	I	$\mathcal{H}$
—	+8303	0	0
112	5816	.16	1.5
262	0	.285	2.7
137	−3041	.392	3.7
101	5284	.538	5.0
79	7037	.705	6.6
73	8658	.94	8.8
57	9923	1.21	11.3
66	11389	1.70	16.0
68	12898	2.70	25.2
41	13808	3.90	36.2
28	14430	4.90	45.9
29	15074	6.65	62.4
19	14652	4.80	45.0
45	13653	2.25	21.1
85	11766	.70	6.6
29	11122	.49	4.6
129	8258	0	0

TABLE III.

RING III: $n_1 = 304$; const. = 141 5; $\mathcal{B} = 16.3d$; $\mathcal{H} = 9.63 \times I$.			
d	$\mathcal{B}$	I	$\mathcal{H}$
—	+9568	0	0
93	8052	.16	1.54
154	5542	.285	2.74
288	848	.36	3.47
107	− 880	.394	3.79
202	4173	.48	4.62
134	6357	.58	5.59
115	8 32	.713	6.87
105	9943	.93	8.96
75	11166	1.19	11.46
77	12421	1.6	15.41
74	13627	2.6	25.04
21	13969	3.2	30.82
49	14768	4.75	45.74
32	15289	6.7	64.52
40	14621	3.75	36.11
41	13953	2.00	19.26
49	13154	1.1	10.59
27	12714	.80	7.70
52	11866	.45	4.33
141	9568	0	0

TABLE IV.

Ring IV; $n_1 = 291$: $c = 141.5$; $\mathcal{B} = 16.5 \times d$; $\mathcal{H} = 9.23 \times I$.			
d	$\mathcal{B}$	I	$\mathcal{H}$
—	+6600	0	0
155	4042	.08	.7
322	−1270	.165	1.5
225	4983	.298	2.75
185	8036	.410	3.8
55	8943	.558	5.2
54	9834	.731	6.75
49	10643	.973	8.98
35	11220	1.248	11.5
39	11864	1.78	16.4
40	12524	2.78	25.7
27	12969	3.98	36.7
44	13695	6.60	60.9
34	13134	4.0	36 9
38	12507	2.11	19.5
60	11517	.9	8.3
59	10544	.5	4.6
20	10214	4	3.7
219	6600	0	0

B. HEATED TO 675° AND QUENCHED.

TABLE V.

RING I; $n_1 = 298$; $c = 135.5$; $\mathfrak{B} = 19\ 5 \times d$; $\mathcal{H} = 9.46 \times I$.

d	$\mathfrak{B}$	I	$\mathcal{H}$
—	+7283	0	0
20.	6893	.3	2.84
9.	6718	.4	3.78
12.5	6474	.58	5.2
17.5	6133	.72	6.81
29	5567	1.00	9.5
105.5	3510	1.42	13 4
201.	− 410	2.15	20.3
128.	2886	2.72	25.7
206.	6903	4.0	37.8
125.	9341	5.10	48.2
116.	11603	7.10	67.2
51.	10608	4.15	39.3
58.	9477	2.18	20.6
39.	8717	1.21	11.4
36.5	8005	.58	5.49
37.	7283	0	0

TABLE VI.

RING II: $n_1 = = 292$; $c = 135.5$; $\mathfrak{B} = 23d$; $\mathcal{H} = 9\ 39 \times I$.

d	$\mathfrak{B}$	I	$\mathcal{H}$
—	+6925	0	0
46.5	5842	.13	1.2
164.	2021	.28	2.0
125.	− 892	.40	3.7
94.	3082	.55	5.2
79.	4923	.70	6.6
74.	6047	.95	8.9
94.	8837	1.42	13.3
78.	10654	2 10	19.7
45.5	11714	2 68	25.2
67.	13275	3.90	30 6
42.5	14265	5.00	47.0
48.	15383	7.08	66.5
52.	14171	4 10	38.5
77.	12377	2.15	20.2
93.	10210	.85	8.0
49.	9068	.45	4 2
54.	7810	.18	1.7
38.	6925	0	0

TABLE VII.

RING III $n_2 = 304$; $c = 135.5$, $\mathfrak{B} = 17.0 \times d$; $\mathcal{H} = 9\ 58 \times I$.

d	$\mathfrak{B}$	I	$\mathcal{H}$
—	+6956	0	0
76	5660	.13	1.2
104	3887	.20	1.9
247	− 324	.28	2.7
155	2966	.40	3.8
127	5131	.52	5.0
95	6751	.70	6.7
80	8115	.95	9.1
97	9769	1.40	13.4
85	11218	2.05	19 6
53	12121	2.60	24 9
81	13502	3.75	35.9
50	14371	4.75	45,5
57	15343	6.50	62.3
65	14236	3.90	37.4
102	12497	2.08	19 9
128	10315	.85	8,14
67	9173	.45	4.3
40	8491	.30	2.9
33	7828	.18	1.7
57	6956	0	0

TABLE VIII.

RING IV; $n_1 = 291$; $c = 135.5$; $\mathfrak{B} = 17.2 \times d$; $\mathcal{H} = 9\ 24 \times I$.

d	$\mathfrak{B}$	I	$\mathcal{H}$
—	+4610	0	0
108	2752	.07	.65
194	− 585	.15	1.39
134	2890	.20	1.85
90	4438	.30	2.77
79	5797	.40	3.70
68	6967	.55	5.08
57	7947	.72	6.65
57	8927	1.00	9 24
86	10406	1.45	13.4
83	11834	2.18	20.1
50	12694	2.75	25.4
65.5	13821	4.00	37.0
34	14406	5.10	47.1
37	15042	7.05	66.1
49	14198	4.2	38.8
97	12530	2.2	20.3
152	9916	.90	8.32
87,5	8411	.48	4.44
114	6450	.18	1.66
107	4610	0	0

TABLE IX.

Ring I.			Ring II.			Ring III.			Ring IV.		
$\mathcal{B}_m$	$\mathcal{B}_r$	$\mathcal{H}$	$\mathcal{B}_m$	$\mathcal{B}_r$	$\mathcal{H}$	$\mathcal{B}_m$	$\mathcal{B}_r$	$\mathcal{H}$	$\mathcal{B}_m$	$\mathcal{B}_r$	$\mathcal{H}$
11603	7283	67.2	15383	6925	66.5	15343	6956	62.3	15042	4610	66.1
8444	5343	35.2	13339	6839	36.6	13671	6913	35.5	14035	4816	35.1
5222	3136	24.1	10858	6454	19.5	11276	6683	19 6	10630	4747	13.7
3783	2165	19.0	9204	5951	13.3	8336	5813	9.1	9133	4592	9.24
1833	819	13.2	7386	5103	8.9	5950	4364	5.0	8273	4489	6.93
527	98	6.3	2318	1526	2.6	4705	3427	3 8	6347	4283	3.70
			594	221	1.7	3401	2412	2.7	3870	2563	1.85
			4928	3530	5.2	1884	1091	1.9	1514	310	.46
			3612	2540	3.7						

C. HEATED TO 900° AND QUENCHED.

TABLE X.

Ring I ; $n_1 = 305$; $c = 115$; $\mathcal{B} = 22.9 \times d$; $\mathcal{H} = 9.68 \times I$.

d	$\mathcal{B}$	I	$\mathcal{H}$
—	+3786	0	0
19.	3351	.66	6.39
6.5	3202	.87	8.42
14.5	2870	1.3	12.6
23.	2344	1.9	18.4
22.	1841	2.32	22.5
66.	331	3.30	31.9
93.	−1797	4.15	40.2
47.	2872	4.52	43 8
87.	4862	5.50	53.2
81.	6715	6.90	66.8
43.	5731	4.00	38.7
36.	4907	2.08	20.1
32.	4175	.65	6.29
17.	3786	0	0

TABLE XI.

Ring II ; $n_1 = 292$; $c = 116$; $\mathcal{B} = 27.4 \times d$; $\mathcal{H} = 9.19 \times I$.

d	$\mathcal{B}$	I	$\mathcal{H}$
—	+8876	0	0
27	8135	.38	3.49
13	7778	.50	4.59
20	7229	.65	5.97
44	6022	.90	8.27
171	1302	1.38	12.68
169	−3336	2.00	18.38
100	6080	2.55	23.43
143	10004	3.70	34.00
62	11705	4.75	43 65
57	13269	6.70	61.6
36	12281	3 90	35.8
54	10799	1.60	14.7
31	9948	.75	6.89
39	8878	0	0

TABLE XII.

Ring III ; $n_1 = 300$; $c = 115$; $\mathcal{B} = 20.3 \times d$; $\mathcal{H} = 9.53 \times I$.

d	$\mathcal{B}$	I	$\mathcal{H}$
—	+8993	0	0
23	8526	.12	1.14
39	7734	.25	2.32
43	6861	.38	3.62
122	4384	.50	4.76
210	121	.65	6.2
166	−3249	.90	8.58
192	7146	1.38	13.15
135	9886	2.00	19.06
69	11287	2.52	24 02
89	13093	3.60	34.59
54	14189	4.65	44.31
66	15529	6.40	61.00
58	14352	3.80	36.21
102	12281	1.60	15 25
66	10941	.75	7.15
34	10251	.40	3.81
62	8992	0	0

TABLE XIII.

Ring IV : $n_1 = 275$; $c = 122$; $\mathcal{B} = 19.3 \times d$; $\mathcal{H} = 8.73 \times I$.

d	$\mathcal{B}$	I	$\mathcal{H}$
—	+4622	0.	0.
94	2808	.072	.63
162	− 319	.125	1.09
122	2672	.195	1.70
83	4275	.268	2.34
71	5645	.368	3.21
59	6784	.495	4 32
51	7768	.660	5.76
52	8772	.865	7.55
75	10219	1.28	11.2
68	11531	1.82	15.9
39	12284	2.25	19.6
54	13326	3.60	31.4
32	13944	4.60	40.1
35	14619	6.30	55.0
44	13770	3.88	33 9
120	11454	1 58	13 8
104	9447	.75	6.55
66	8173	.42	3.67
105	6147	.122	1.07
79	4622	0.	0.

TABLE XIV.

Ring I.			Ring II.			Ring III.			Ring IV.		
$\mathcal{B}_m$	$\mathcal{B}_r$	$\mathcal{H}$	$\mathcal{B}_m$	$\mathcal{B}_r$	$\mathcal{H}$	$\mathcal{B}_m$	$\mathcal{B}_r$	$\mathcal{H}$	$\mathcal{B}_m$	$\mathcal{B}_r$	$\mathcal{H}$
6715	3786	66.8	13268	8875	61.6	15529	8993	61.0	14629	4032	55.0
5193	2700	53.2	11731	8219	43.7	14180	8821	44.3	13510	4825	32.0
3580	1453	44.3	10291	7300	33.8	13134	8648	34.6	11696	4786	17.5
1990	480	31.9	7684	5434	23.0	11784	8313	24.0	8850	4584	7.94
927	114	18.4	6216	4212	18.2	10343	7460	19.1	6929	4053	4.52
389	23	8.6	3818	2401	12.1	8292	6161	13.15	4883	3146	2.36
207	3	5.0	1825	919	8.09	6029	4486	8.58	2470	1602	1.07
			933	306	5.97	4273	2974	6.2	1038	546	.63
			370	69	3.49	2690	1695	4.76			
						1238	648	3.8			
						650	203	2.32			
						264	41	1.72			

D. TEMPERATURE FOR ONE HOUR AT 100°.

TABLE XV.

Ring I; $n_1 = 305$; $c = 147$; $\mathcal{B} = 17.9 \times d$; $\mathcal{H} = 9.68 \times I$.

d	$\mathcal{B}$	I	$\mathcal{H}$
—	+3714	0	0
42	2952	.985	9.53
27	2469	1.5	14.5
52	1538	2.3	22.3
65	374	3.06	29.6
86	−1165	3.70	35.8
141	3689	4.66	45.1
160	6543	6.5	62.9
14	6292	5.66	54.8
86	4753	1.9	18.4
25	4306	1.00	9.7
15	4037	.51	4.9
18	3715	0	0

TABLE XVI.

Ring II; $n_1 = 292$; $c = 119$; $\mathcal{B} = 26.75 \times d$; $\mathcal{H} = 9.19 \times I$.

d	$\mathcal{B}$	I	$\mathcal{H}$
—	+8719	0	0
45	7515	.531	4.88
23	6900	.703	6.46
52	5509	.938	8.62
180	694	1.414	13.00
171	−3880	2.09	19.20
99	6528	2.66	24.44
135	10139	3.93	36.12
58	11690	5.07	46.59
57	13215	7.2	66.17
38	12197	4.15	38.14
56	10699	1.65	15.16
26	10003	.832	7.65
20	9468	.488	4.48
28	8719	0	0

TABLE XVII.

Ring III; $n_1 = 300$; c 119; $\mathcal{B} = 19.6 \times d$; $\mathcal{H} = 9.53 \times I$.

d	$\mathcal{B}$	I	$\mathcal{H}$
—	+8507	0	0
67	7174	.278	2.65
47	6253	.388	3.70
147	3372	.534	5.09
195	− 450	.707	6.74
155	3488	.940	8.96
183	7075	1.412	13.46
127	9564	2.08	19.82
65	10838	2.63	25.05
87	12543	3.83	36.51
52	13562	4.92	46.89
66	14856	6.9	65.75
59	13701	4.08	38.88
102	11702	1.66	15.50
51	10702	.935	8.92
43	9859	.492	4.69
69	8507	0	0

TABLE XVIII.

Rnig IV; $n_1 = 275$; $c = 136$; $\mathcal{B} = 17.3 \times d$; $\mathcal{H} = 8.73 \times I$.

d	$\mathcal{B}$	I	$\mathcal{H}$
—	+4921	0	0
125.5	2750	.08	.70
152.	120	.129	1.13
144.	−2371	.200	1.75
97.	4049	.277	2.42
86.5	5545	.388	3.39
71.	6773	.532	4.64
60.	7811	.705	6.15
60.	8849	.938	8.19
87.	10354	1.410	12.31
80.	11738	2.10	18.33
46.	12534	2.65	23.13
63.	13624	3.88	33.87
34.	14212	5.00	34.65
38.	14869	7.01	61.20
48.	14038	4.11	35.9
129.	11806	1.67	14.6
148.	9246	.623	5.44
139.	6841	.174	1.52
111.	4921	0	0

TABLE XIX.

RING I.			RING II.			RING III.			RING IV.		
$\mathcal{B}_m$	$\mathcal{B}_r$	$\mathcal{H}$	$\mathcal{B}_m$	$\mathcal{B}_r$	$\mathcal{H}$	$\mathcal{B}_m$	$\mathcal{B}_r$	$\mathcal{H}$	$\mathcal{B}_m$	$\mathcal{B}_r$	$\mathcal{H}$
6543	3714	62.9	13215	8721	66 2	14857	8487	65.7	14868	4921	61.2
3813	1718	45.1	11690	8078	46.3	12573	8222	36 3	12568	4904	23.3
2542	788	35.9	10339	7303	35.8	9918	7174	19 8	10392	4794	12.35
1898	403	29.2	7944	5644	24.4	7987	5939	13.34	7923	4429	6.17
1235	179	22.3	6393	4440	19.2	5860	4371	8.92	5951	3702	3.40
734	72	14 7	4066	2675	12.96	4253	3077	7.00	3720	2457	1.75
292	14	6.56	1832	923	8 58	2675	1754	5.04	2405	1557	1.05
134	9	3.05	589	134	4.87	1215	568	3.65	1263	727	.72
			254	27	2.55	617	186	2.65			

G. TEMPERATURE AT 200°.

TABLE XX.

RING I; $n_1 = 292$; $c = 114$; $\mathcal{B} = 23.1 \times d$; $\mathcal{H} = 9.27 \times I$.			
d	$\mathcal{B}$	I	$\mathcal{H}$
—	+4662	0	0
17.5	4258	.515	4.78
5	4143	.685	6.35
9	3935	.915	8 48
20	3473	1.385	12.8
33	2711	2.05	19.
36	1880	2.60	24.1
136	—1258	3 8	35.2
146	4627	4 9	45.4
139	7834	6.9	64.0
44	6820	4.00	37.3
49.5	5690	1.60	14 8
26	5078	.612	5.67
18	4663	0	0

TABLE XXI.

RING I.		
$\mathcal{B}_m$	$\mathcal{B}_r$	$\mathcal{H}$
7834	4662	64.0
5215	2665	45.4
3211	1205	35.2
1655	339	24.0
462	46	8.44
166	5	3.5

H. TEMPERED AT 300.°

TABLE XXII.

RING I; $n_1 = 300$; $c = 127$; $\mathcal{B} = 20.7 \times d$; $\mathcal{H} = 9.56 \times I$.			
d	$\mathcal{B}$	I	$\mathcal{H}$
—	+8931	0	0
63	7628	.922	8.81
43	6738	1.401	13.38
82	5041	2.09	19.98
127	2412	2.64	25 24
275	—3281	3.14	30.02
250	8455	3.79	36.2
134	11229	4.94	47.2
97	13237	6.95	66.4
38	12450	4.8	45.9
88	10628	1.76	16.8
82	8931	0	0

TABLE XXIII.

RING II; $n_1 = 300$; $c = 129$; $\mathcal{B} = 24.7 \times d$; $\mathcal{H} = 9.44 \times I$.			
d	$\mathcal{B}$	I	$\mathcal{H}$
—	+9399	0	0
60	7916	.506	4.78
27	7249	.670	6.32
74	5421	.890	8.40
164	1370	1.155	11.13
242	—4607	1.60	15.10
127	7744	1.99	18.79
86	9868	2.49	23.5
85	11968	3.60	34.0
42	13005	4.62	43.6
48	14190	6.42	60.6
37	13276	3.8	35.9
72	11498	1.338	12.65
43	10436	.550	5.19
42	9399	0	0

TABLE XXIV.

Ring III; $n_1 = 295$; $c = 129$; $\mathcal{B} = 18.1 \times d$; $\mathcal{H} = 9.69 \times I$.

d	$\mathcal{B}$	I	$\mathcal{H}$
—	+8905	0	0
58.	7855	.263	2 55
33.	7258	.370	3.58
66.	6063	.505	4.89
225.	1990	.670	6.49
226.	—2101	.890	8.62
255.	6717	1.352	13.08
161.	9631	2.00	19.4
73.	10952	2.55	24.7
93.	12635	3.72	36.0
56.5	13658	4 80	46.5
70.5	14934	6.78	65.7
59.	13866	3.92	38.0
125.	11603	1.34	13.0
72.	10300	.550	5.33
77.	8906	0	0

TABLE XXV.

Ring IV; $n_1 = 300$; $c = 128$; $\mathcal{B} = 18.4 \times d$; $\mathcal{H} = 9.52 \times I$.

d	$\mathcal{B}$	I	$\mathcal{H}$
—	+5640	0	0
127.	3303	.077	.73
156.	433	.120	1.14
153.	—2382	.192	1.83
101.	4240	.267	2.54
90.	5896	.375	3 57
70.	7184	.510	4.86
61.	8306	.674	6.42
62.	9447	.897	8.54
87.	11048	1.355	12.9
73.	12391	2.00	19.0
38.	13090	2.51	23.9
44.5	13909	3.6	34 3
23.	14332	4.6	43 8
27.	14829	6.3	60.
32.5	14232	3.82	36.4
57.	13184	2.02	19.2
96.	11417	1.02	9 71
99.	9595	.49	4.66
111.	7553	.154	1.47
105.	5621	0	0

TABLE XXVI.

Ring I.			Ring II.			Ring III.			Ring IV.		
$\mathcal{B}_m$	$\mathcal{B}_r$	$\mathcal{H}$	$\mathcal{B}_m$	$\mathcal{B}_r$	$\mathcal{H}$	$\mathcal{B}_m$	$\mathcal{B}_r$	$\mathcal{H}$	$\mathcal{B}_m$	$\mathcal{B}_r$	$\mathcal{H}$
13237	8932	66.4	14190	9399	60.6	14934	8905	65.7	14830	5640	60.0
11168	7628	46 5	12029	8793	34.0	12679	8624	36.2	12402	5612	19.0
9656	6552	35.6	8596	6595	18.9	9909	7475	19.4	8409	5031	6.4
7214	4398	29.25	6793	5064	15.1	7792	6036	13.1	5161	3542	2.5
3926	1610	24.85	3940	2680	11.13	5190	3969	8.65	2511	1739	1.13
			2186	1223	8.4	3310	2367	6.5			
						1548	869	4.9			

I. TEMPERED AT 450°.

TABLE XXVII.

Ring I; $n_1 = 300$; $c = 127$; $\mathcal{B} = 20.7 \times d$; $\mathcal{H} = 9.56 \times I$.

d	$\mathcal{B}$	I	$\mathcal{H}$
—	+12198	0	0
37	11431	.513	4 92
15	11121	.676	6 44
26	10583	.900	8.6
87	8782	1.368	13.1
85	7022	1.62	15.5
95	5056	1 80	17.2
98	3027	1.89	18 1
250	—2143	2.00	19 1
211	6516	2.17	20.7
123	9062	2.35	22.5
94	11008	2.68	25 6
65	12359	3.22	30.8
69	13782	4.48	42 8
62	15065	7.00	66.9
69	13637	2.00	19.1
25	13119	1.015	9 7
44.5	12198	0	0

TABLE XXVIII.

Ring II; $n_1 = 300$; $c = 127$; $\mathcal{B} = 25.1 \times d$; $\mathcal{H} = 9.44 \times I$.

d	$\mathcal{B}$	I	$\mathcal{H}$
—	+11207	0	0
88	8998	.51	4.81
54	7643	.673	6.35
163	3552	.895	8.45
130	289	1.011	9.53
145	—3351	1.157	10.9
133	6689	1.352	12.74
173	11031	2.00	18.88
57	12462	2.54	24.0
61	13993	3.65	34.46
31	14771	4.7	44 37
34	15624	6.49	61.3
28	14921	3 86	36.4
48	13716	1.6	15.1
36	12812	.754	7.12
64	11206	0	0

TABLE XXIX.

RING III; $n_1 = 300$; $c = 127$; $\mathcal{B} = 18.4 \times d$; $\mathcal{H} \times 9.53 \times I$.			
d	$\mathcal{B}$	I	$\mathcal{H}$
—	+9890	0	0
36	9228	.136	1.3
112	7167	.373	3.55
220	3119	.51	4 86
200	— 561	.626	5.97
60	1665	.676	6.44
221	5731	.90	8 58
222	9816	1.368	13.1
123	12079	2.03	19.3
58	13146	2.6	24.8
75	14526	3.8	36.2
41	15280	4.88	46.5
42	16053	6.82	65.0
38	15354	4.02	38.3
93	13643	1.62	15.44
61	12521	.902	8.60
57	11472	.459	4.37
86	9890	0	0

TABLE XXX.

RING IV: $n_1 = 300$; $c = 126$; $\mathcal{B} = 18.7 \times d$; $\mathcal{H} = 9.52 \times I$.			
d	$\mathcal{B}$	I	$\mathcal{H}$
—	+6189	0	0
139	3590	.078	74
175	318	.120	1.14
175	—2954	.190	1.81
112	5049	.262	2 49
102	6956	.375	3.57
76	8377	.570	5.43
66	9611	.673	6.41
66	10845	.896	8.53
79	12322	1.35	12.85
46	13182	2.00	19.0
19	13537	2.54	24.2
25	14005	3 60	35.3
17	14323	4.60	43.8
23	14753	6 26	59.7
47	13874	2.60	24.8
46	13014	1.15	10.95
73	11649	.649	6.18
163	8601	.169	1.61
129	6189	0	0

TABLE XXXI.

RING I.			RING II.			RING III.			RING IV.		
$\mathcal{B}_m$	$\mathcal{B}_r$	$\mathcal{H}$	$\mathcal{B}_m$	$\mathcal{B}_r$	$\mathcal{H}$	$\mathcal{B}_m$	$\mathcal{B}_r$	$\mathcal{H}$	$\mathcal{B}_m$	$\mathcal{B}_r$	$\mathcal{H}$
15065	12198	66.9	15624	11207	61.3	16053	9890	65.0	14753	6189	59.7
12689	10536	31 0	13855	10617	34.4	14545	9743	36.2	10892	5975	8.49
10205	8197	22 2	11031	8923	18 9	10966	8446	15.6	7237	4825	3.54
6231	4347	18 35	7932	6350	12.74	9052	7231	11.25	2552	1748	1.14
3167	1615	15.5	4616	3388	9.5	6357	4996	7.8			
932	186	8.68	1852	1000	6.89	4811	3670	6.00			
			803	276	4.81	2668	1766	4.38			
						530	153	2 28			

K. ANNEALED.

TABLE XXXII.

RING I; $n_1 = 300$; $c = 127$; $\mathcal{B} = 21.5 \times d$; $\mathcal{H} = 9.54 \times I$.			
d	$\mathcal{B}$	I	$\mathcal{H}$
—	+6751	0	0
115	4278	.500	4.77
77	2623	.66	6.3
133	— 237	.88	8.4
181	4128	1.331	12.7
128	6880	2.00	19.1
67	8321	2.52	24.0
95	10363	3.62	34.5
60	11653	4.62	44.1
75	13266	6.42	61.2
45	12298	3.81	36.3
101	10127	1.57	15.0
52	9009	.89	8.5
45	8041	.45	4.29
60	6751	0	0

TABLE XXXIII.

RING II; $n_1 = 300$; $c = 127$; $\mathcal{B} = 25.5 \times d$; $\mathcal{H} = 9.44 \times I$.			
d	$\mathcal{B}$	I	$\mathcal{H}$
—	+10838	0	0
99	8313	.190	1.79
147	4565	.265	2.50
250	— 1810	.370	3.49
146	5533	.500	4 72
94	7930	.660	6.23
71.5	9753	.878	8.29
74	11640	1.328	12.55
50	12915	2.00	18.9
24	13527	2 50	23.6
33	14369	3.60	34.0
20	14879	4.60	43.4
25	15520	6.30	59.5
27	14841	3.78	35.7
42	13770	1.55	14.63
31	12980	.745	7.03
22	12419	.418	3.95
62	10838	0	0

TABLE XXXIV.

RING III; $n_1 = 300$; $c = 127$; $\mathcal{B} = 18.8 \times d$; $\mathcal{H} = 9\ 52 \times I$.

d	$\mathcal{B}$	I	$\mathcal{H}$
—	+10105	0	0
85	8507	.110	1.05
84	6928	.170	1.62
212	2942	.230	2.19
142	272	.27	2.57
262	− 4635	.371	3.53
158	7605	.506	4.81
99	9469	.669	6.37
78	10932	.888	8.36
82	12474	1.349	12.84
56	13527	2.10	20.0
28	14053	2.59	24.6
38	14767	3.75	35.7
23	15199	4.84	46.0
31	15782	6.8	65.0
35	15124	3.99	38.0
53	14128	1.60	15.23
35	13470	.885	8.43
32	12868	.550	5.23
147	10104	0	0

TABLE XXXV.

RING IV; $n_1 = 300$; $c = 127$: $\mathcal{B} = 19.0 \times d$; $\mathcal{H} = 9.52 \times I$.

d	$\mathcal{B}$	I	$\mathcal{H}$
—	+6764	0	0
143	4047	.055	.53
222	− 171	.085	.84
140	2831	.116	1.10
142	5529	.182	1.73
69	6840	.258	2.45
54.5	7876	.365	3.47
37.5	8588	.50	4.76
28.5	9130	.66	6.28
25	9605	.876	8.34
29.5	10165	1.322	12.68
22	10583	1.95	18.6
32	11191	3.55	33.8
33.5	11828	6.10	58.1
44	10992	2.54	24.2
27	10479	1.278	12.19
20.5	10089	.782	7.44
21	9690	.508	4.84
48	8770	.200	1.9
38	8056	.09	.86
68	6764	0	0

TABLE XXXVI.

RING I.			RING II.			RING III.			RING IV.		
$\mathcal{B}_m$	$\mathcal{B}_r$	$\mathcal{H}$	$\mathcal{B}_m$	$\mathcal{B}_r$	$\mathcal{H}$	$\mathcal{B}_m$	$\mathcal{B}_r$	$\mathcal{H}$	$\mathcal{B}_m$	$\mathcal{B}_r$	$\mathcal{H}$
13266	6751	61.2	15520	10838	59.5	15782	10105	65.0	11828	6764	58.1
10428	6343	36.3	13490	10277	23.6	14645	9926	35.8	10298	6802	12.45
8546	5686	24.0	10226	8237	8.30	12446	9475	12.8	8854	6403	4.75
5278	3795	12.8	7319	5840	4.72	9673	7830	6.28	6270	4931	1.74
3064	2118	8.48	5317	4066	3 49	6514	5349	3.51	4636	3610	1.12
1866	1178	6.37	2754	1811	2.50	4033	3149	2.50	3268	2508	.82
537	193	3.53	1033	446	1.79	2613	1871	2.17	665	247	.52
						1156	686	1.61			

L. RE-ANNEALED.

TABLE XXXVII.

RING II.			RING III.		
$\mathcal{B}_m$	$\mathcal{B}_r$	$\mathcal{H}$	$\mathcal{B}_m$	$\mathcal{B}_r$	$\mathcal{H}$
14813	7717	61.0	15517	9507	59.0
13611	7691	35.9	13438	9299	18.2
10993	7274	16.25	10943	8259	8.08
8615	6085	8.69	8240	6615	4.59
7033	5161	6.14	6502	5207	3.36
3605	2543	3.21	3969	3005	2.59
936	405	1.89	2552	1843	2.0
			1087	633	1.48

TABLE 1A.

RING I.		
$\mathcal{B}_m$	$\mathcal{B}_r$	$\mathcal{H}$
13847	7966	61.5
13315	7960	48.7
12180	7956	37.8
10120	7104	26.3
7112	5293	16.2
3639	2481	10.2
1425	724	7.1

A. Rings in the original state.

The measurements of rings gave the following data:

	Ring I,	Ring II.	Ring III.	Ring IV.
Mean diameter.....	12.607 cm.	12.699 cm.	12.63 cm.	12.607 cm.
Volume	95.099 cm^3	80 637 cm^3	109.29 cm^3	107.99 cm^3
Cross-section.......	2.401 cm^2	2.021 cm^2	2.754 cm^2	2.727 cm^2

As I stated before, these measurements were repeated every time after the rings had been subjected to a high temperature, so after the following steps: B, C, K and L. Each time a small decrease of the cross-section was observed.

In the original state, the hysteresis curves for only one maximum magnetizing field ($\mathcal{H}$) of about 60 were determined, except for Ring I, for which the value of $\mathcal{H}$ was varied.

The hysteresis curves show strongly the influence of carbon, the area of the loops diminishing with the decreasing percentage of carbon. The mild steel shows, indeed, a curve very similar to that of wrought iron. The maximum induction, taking the rings in the order I, II, III, has the values: 13840, 15070, 15290 lines of magnetic force, while the magnetizing force was very nearly the same in all cases. The corresponding coercive forces are 8.6, 2.7 and 3.6.

B. *Rings heated to* 675° *and quenched.*—The rings were then introduced into furnaces, which were well heated beforehand. On the bottom of the muffles was put a sheet of asbestos and over this two strips of the same material, on which the ring was placed. In order to prevent oxidation as much as possible, charcoal was put in the opening of the muffle. The heating to a dull cherry-red took about eight minutes. Then the ring was withdrawn quickly and quenched in water at 5° C.

Ring I has become magnetically harder, *i. e.*, the maximum induction for the same magnetizing field has decreased, the permeability, especially for low fields, is smaller, and the coercive force increased to more than twice its original value.

The iron ring shows an increase in permeability, which may be explained by a previous mechanical hardening, when it was turned to its proper shape.

In rings II and III there is no sign of magnetic hardening, the principal influence of this treatment being the remarkable drop of the remanence, while the maximum induction remained almost unchanged. The permeability, on the other hand, decreased a little. This sudden and unexpected drop in retentivity will again be met later on and discussed there more fully.

It is apparent that we have not passed the temperature at which low carbon steel is hardened. It is well known that the second and third point of recalescence for low carbon steel lie at a higher temperature than the corresponding point in the high carbon steel, which apparently had already been passed in the case of the high carbon steel. It is, therefore, probable, though I do not consider this experiment as an absolute proof, that the magnetic hardening takes place when steel is quenched after it has been heated to the same temperature at which recalescence occurs, *i. e.*, the critical temperature, at which, according to Hopkinson and others, iron loses its magnetic properties.

C. *Rings heated to a little above* 900° *and quenched in ice-water of* 5°.—The heat treatment was the same as in B, but the temperature was raised beyond the third point of recalescence of the low carbon rings.

All the steel rings show the hardening effect, the same being the smaller the less carbon the steel contained.

The high carbon ring (I) shows a decided increase in the hysteresis loss, which is much greater than the increase due to the first heating. While the first time the temperature was raised only a little beyond the point of recalescence, it was this time at least 250° higher. *We draw therefrom the important conclusion that steel becomes magnetically the harder, the more the temperature is raised beyond the recalescent point.* The passing of this point by only a few degrees is not sufficient for the maximum effect.

The hysteresis curves for the steel rings are given on Figs. 1–3, the maximum induction ($\mathfrak{B}_m$) and remanence ($\mathfrak{B}_r$) as a function of the magnetizing force on Fig. 4, and $\mathfrak{B}_r$ as a function of $\mathfrak{B}_m$ on Fig. 5.

D. *Rings reheated to* 100° *for one hour.*—The corresponding curves are marked by crosses on the plates and are drawn only for the low carbon rings, the change being very small for the high carbon steel. The influence of this step becomes more apparent the less carbon the steel contains, and *it consists in a lowering of* $\mathcal{B}_m$ *as well as* $\mathcal{B}_r$ in Rings II. and III., and in a slight raising of the same quantities in Ring I. The coercive force in III. has become slightly larger. *The low carbon steel becomes, therefore, magnetically harder when it is reheated to* 100°. This result is consistent with the observations of Barus and others, mentioned above.

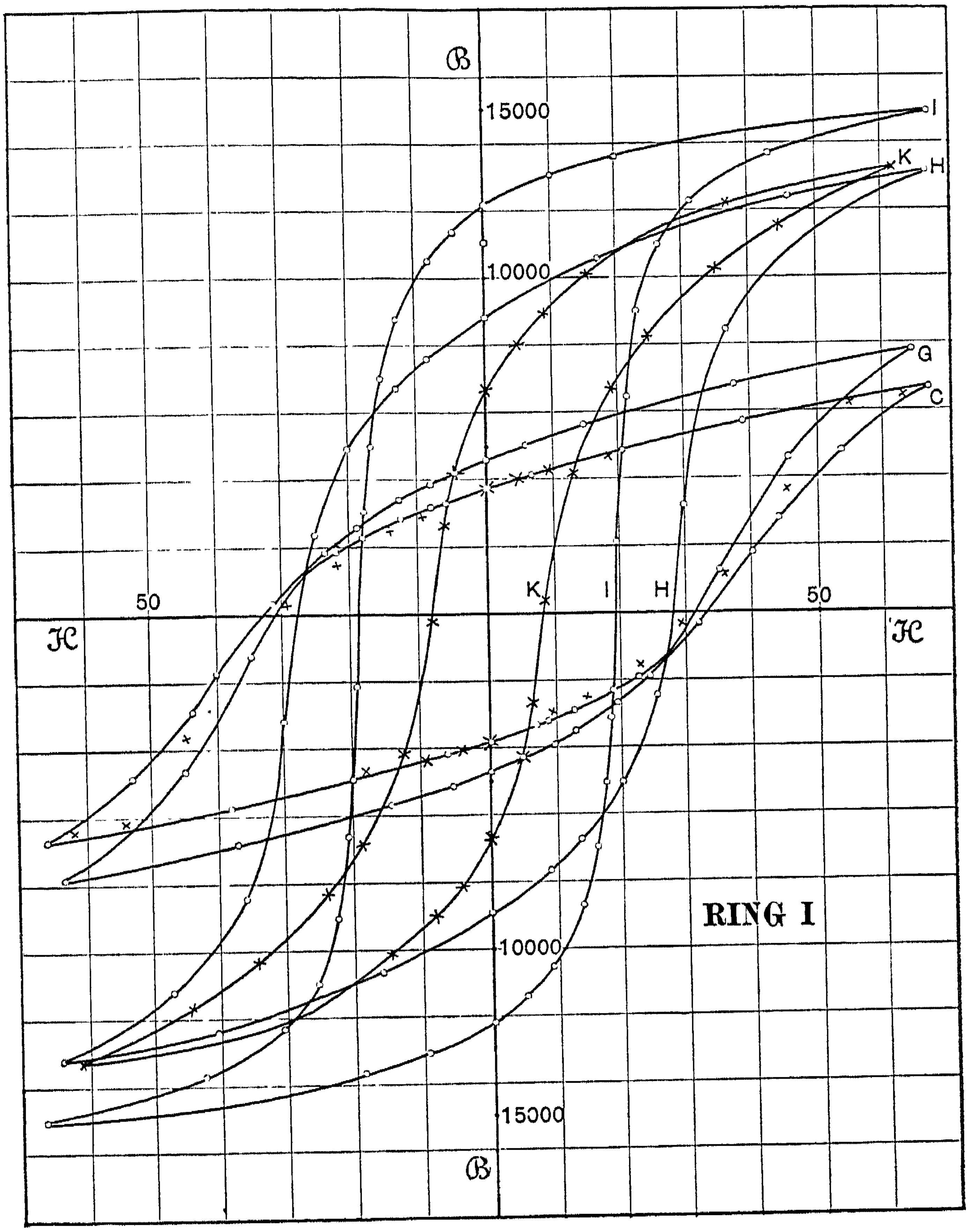

Fig. 1.

E. *and* F. *Rings were heated to* 100° *for* 24 *hours.*—The heat treatment was the same as in the preceding case, except that the time of the heating was increased. I do not give the results, since no decided change takes place. The curves almost coincide with the preceding ones, though there is an unmistakable increase of permeability, especially for small magnetizing fields, this change being largest for the high carbon steel. We have, therefore, a more or less pronounced influence of the time during which the rings were subjected to this temperature, consisting in a slight increase of permeability.

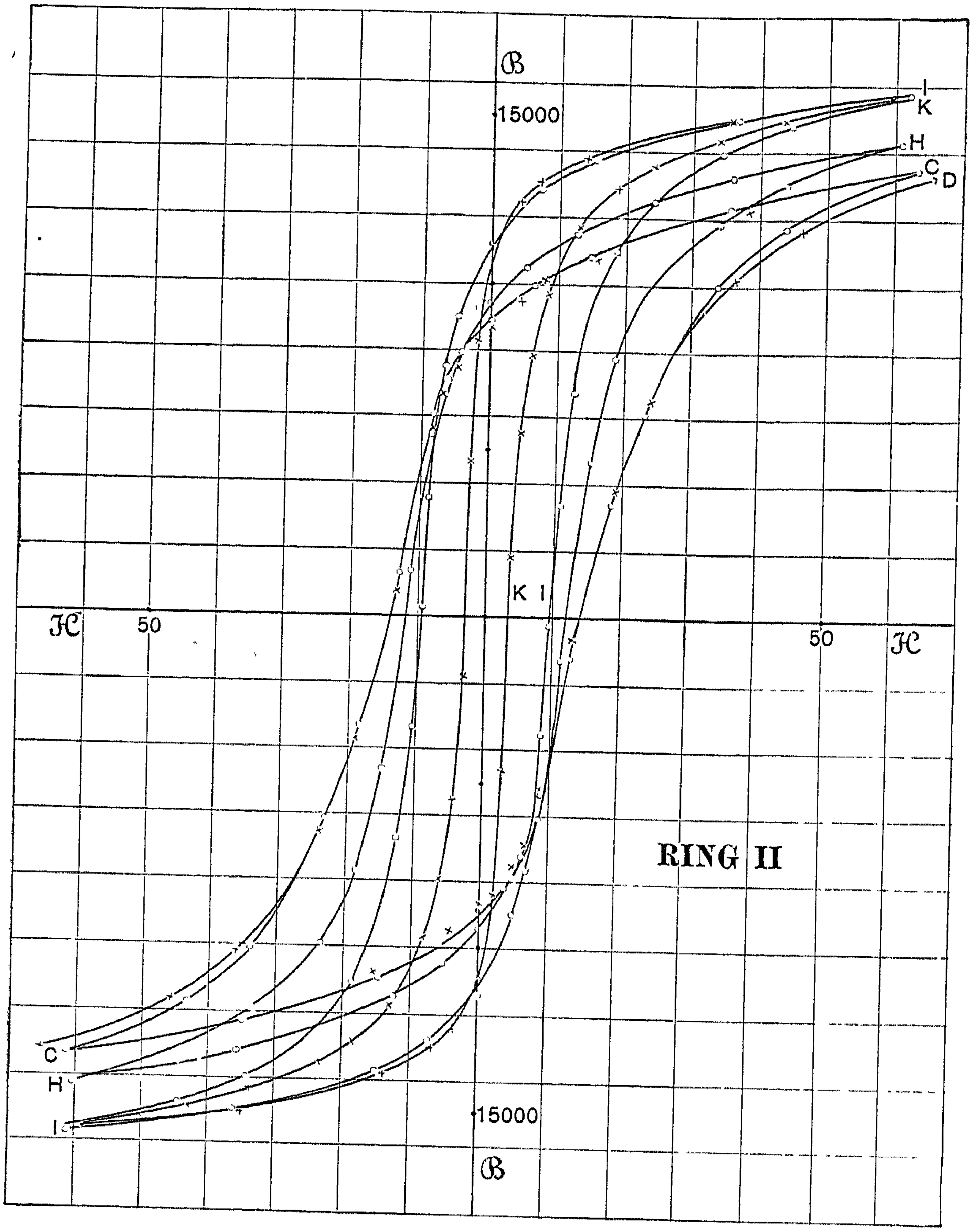

Fig. 2.

G. *Rings reheated to* 200°.—Apparatus for the heat treatment: On the top of the heating table were placed two strips of asbestos, on this a disk of the same material with a round hole in the middle, then a layer of iron turnings and on this the ring. The whole was surrounded with an asbestos ring, which was filled with iron turnings, so that the ring was entirely imbedded in the same. The temperature was read by means of a thermometer, which was placed so as to touch the ring inside. By the arrangement described, uniform distribution of heat from the centre was procured. As soon as the temperature rose to 200° the ring was withdrawn and allowed to cool in the air.

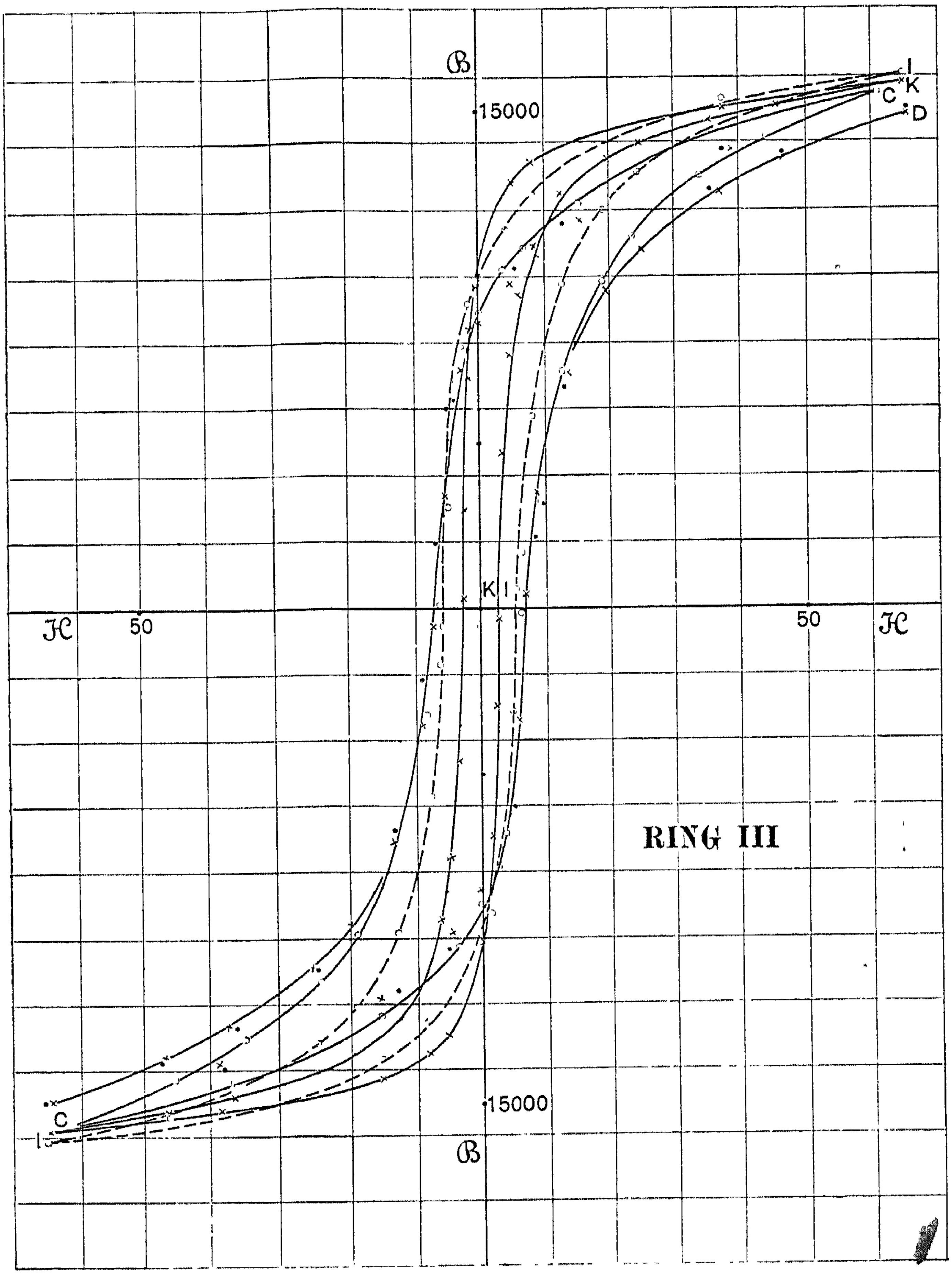

FIG. 3.

I give the results for Ring I. only, the others showing a very small increase in magnetic induction.

We will see from the comparison with the data given later on that the increase of induction is comparatively small in all rings.

H. *Rings reheated to* 300°.—The heat treatment was practically the same as in G.

All rings show a decided increase in permeability, the change

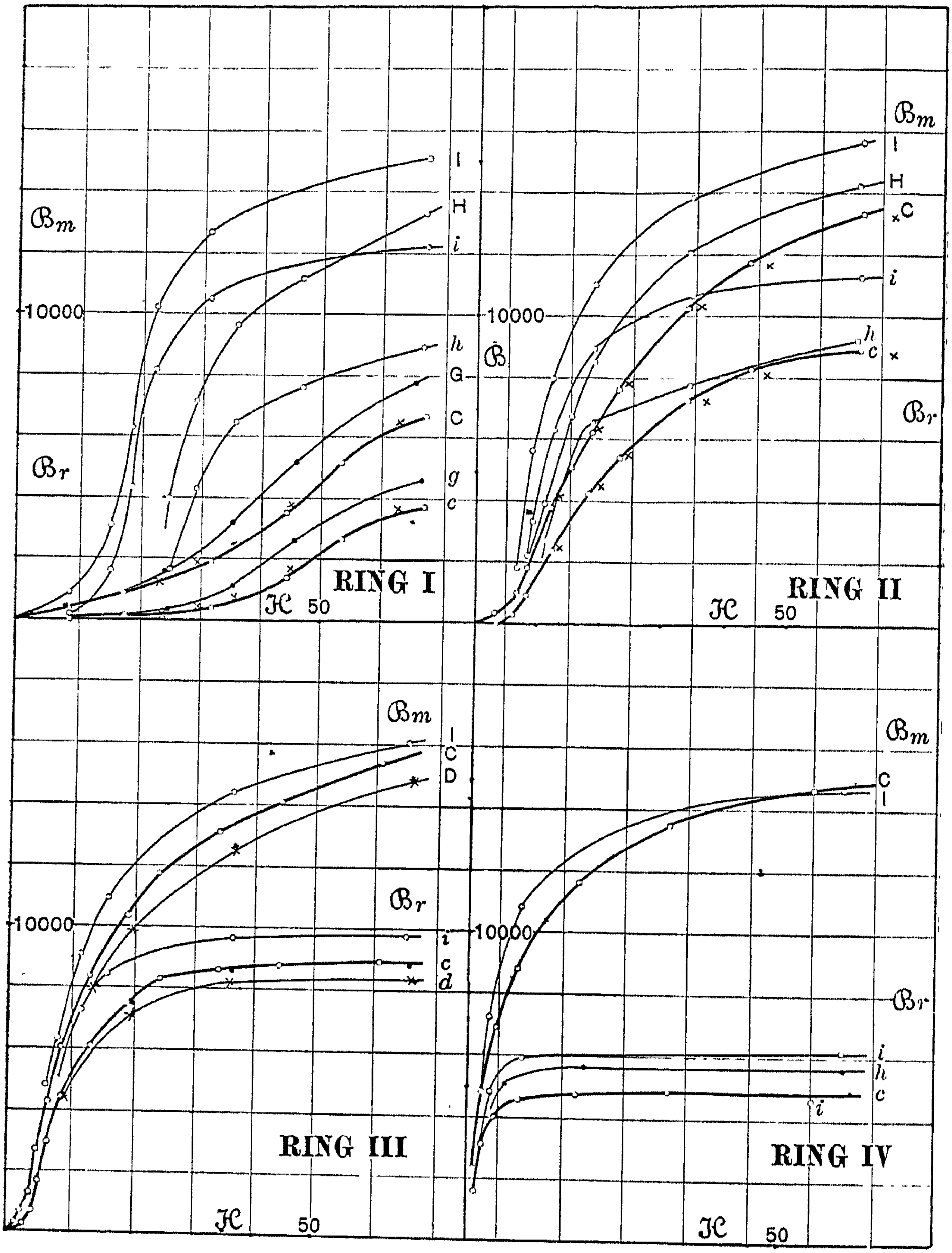

FIG. 4.

being the smaller the less carbon the steel contains. The curve for Ring III., indeed, coincides so nearly with that of the hardened ring that the points corresponding to this step could be indicated only by dots in the plates. The wrought iron ring, that so far showed no sign of a change, has a larger permeability for small fields than it had before. By comparing the curves on Fig. 4, we see a decided tendency towards an increase of the remanence for any given value of maximum induction. This will become more and more decided as we increase the temperature to which the rings are reheated.

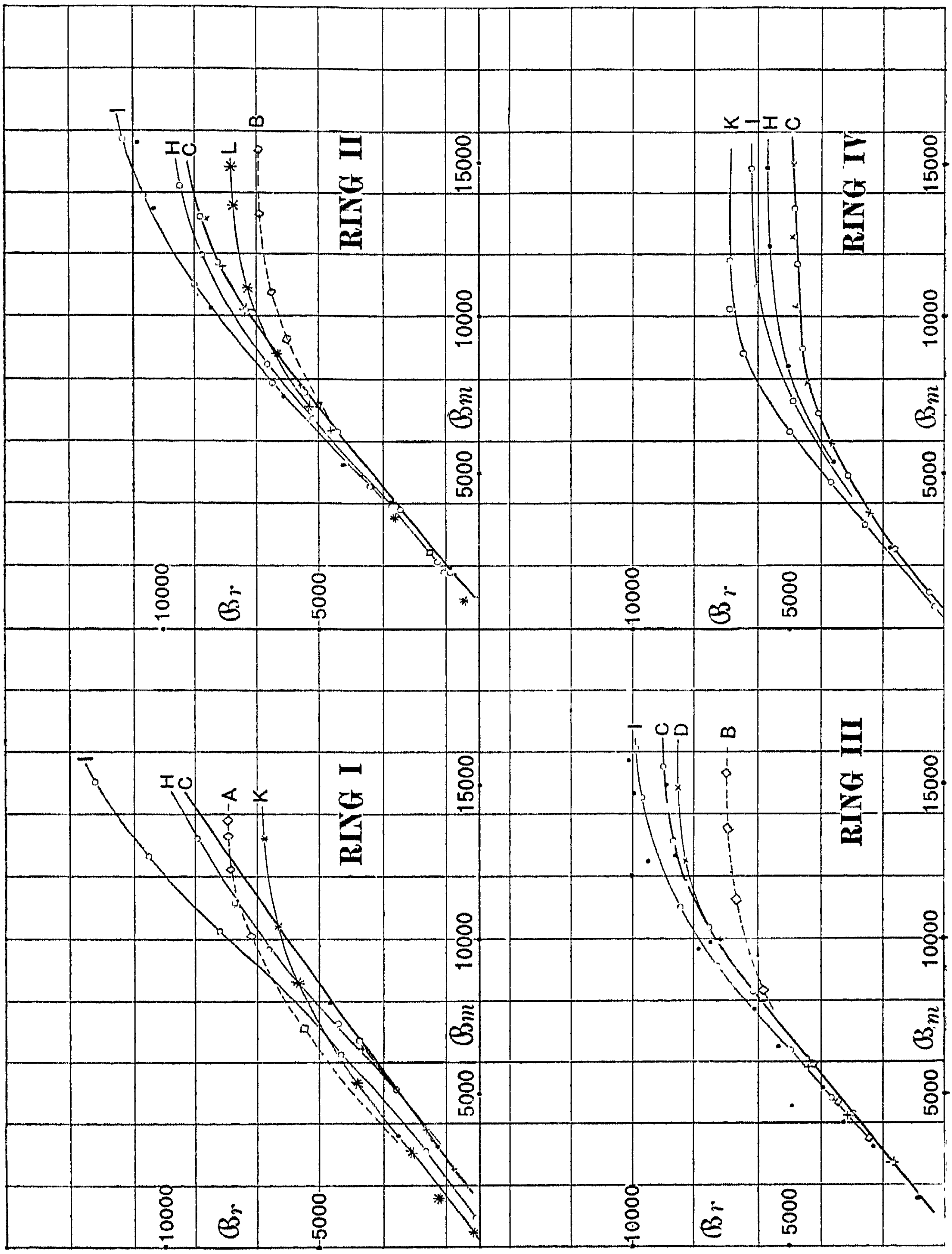

FIG. 5.

The most important and rather unexpected result of this step is the sudden very large increase in the maximum induction of Ring I. The number of lines of magnetic force has almost reached the value the ring had before it was heated at all. Therefore, whatever change in the chemical or physical constitution of the ring produces the change in the magnetic properties, it is largest for the high carbon ring between 200° and 300°, *i. e.*, at a temperature which corresponds to that of the blue temper of steel.

I. *Heated to* 450°.—Heat treatment was practically the same as in G.

We observe a further increase of permeability and induction for all rings. The change for Ring I. is only about one-third of the one in the preceding case, while we have a comparatively large change for Rings II. and III., corresponding to the large difference in $\mathfrak{B}_m$ of Ring I., observed before, and to be attributed to the same causes.

It is to be noticed that, though the magnetic flux has practically reached its maximum for the field strength used, the value of the coercive force is still quite large in comparison with the corresponding value for the rings in the original state. The remanence for Ring I. is larger after this step than in any other. The substance is Crescent steel, *i. e.*, magnet steel. It is apparent that, *in order to make strong magnets, it will be advisable to reheat the quenched steel to about* 450°. The magnets could be made more than twice as strong as if simply the hardened steel is used. Though I worked with closed magnetic circuits, the influence of the ends of the magnets will be the same in the two cases. It is of importance that the coercive force did not decrease nearly as fast as the remanence increased. Another factor in the making of magnets is their permanency. I mentioned the usual method of making permanent magnets in the introduction, and think that a similar treatment, by extending the range of temperature to 450°, will ensure permanency and produce stronger magnets.

K. *Rings annealed.*—The rings were again placed in muffles and heated to a bright red heat, the arrangement being the same as in B and C. After the temperature of about 850° was reached, the fire was banked and the rings allowed to cool inside the muffles. Charcoal was put in the mouth of the muffles. This treatment took about 24 hours.

The rings have become magnetically soft. While in the Rings II. and III. the saturation point was practically the same as before, the coercive force decreased to its smallest value, this last step being the largest in the whole series for the coercive force.

In the high carbon steel and the wrought iron, we find a remarkable decrease in $\mathfrak{B}_m$, accompanied in Ring I. by a still greater decrease of $\mathfrak{B}_r$, while in the iron $\mathfrak{B}_r$ increases with respect to $\mathfrak{B}_m$. These changes can very plainly be observed on Fig. 5, where $\mathfrak{B}_r$ is plotted as a function of $\mathfrak{B}_m$. The curve obtained for Ring I. differs entirely from any of the curves taken after the ring was hardened, but it shows a great similarity to curve A taken in the original state.

Hoping to obtain similar curves for the other two steel rings they were again annealed, the temperature this time being raised to nearly 1000°. Cooling took place in the same way as before.

L. *Reannealed.*

Both rings show the decided decrease of $\mathfrak{B}_r$ and the different character of the curve. The one for Ring III. is indicated by dots only, and coincides partly with curve I. In both cases there is a great similarity with the curves B, obtained by heating the originally annealed steel to a high temperature below the point of recalescence and suddenly quenching. It almost seems that the steel by this process has become a different substance. These curves show more the characteristics of the iron (see ring IV. on Fig. 5) than of steel. Houston and Kennelly's law does not hold for nearly as wide a range as before. I believe that the effect observed in the last step is not an immediate effect of annealing, but that it is the conditions under which cooling takes place, that influence largely the retentivity of steel.

Steel heated to a high temperature below the point of recalescence and suddenly quenched as in B, *will very easily lose its magnetism.* This seems to me of practical importance. The maximum induction being the same, and the remanence a great deal smaller than in the ordinary state, it is apparent that the hysteresis loss will be much smaller, and therefore very mild steel, as our Ring III., treated in the way indicated above, is preferable to the ordinary mild steel used in transformers or other instruments, in which cyclic processes take place, if the induction is carried to high values.

Since the hysteresis loss has been found to increase appreciably in transformers after they have been used for some time, it is of great importance to investigate whether a similar effect takes place in steel treated in the manner suggested. A series of such experiments would be very valuable from a practical point of view.

In 1890, Osmond (*Phil. Mag.* 29, 511, 1890) advanced a theory according to which a bar of steel consists of an intimate mixture of α iron (magnetic) and β iron (unmagnetic). He considers the β modification as forming in a steel a porous framework, the ratio between the amount of α iron and β iron not changing under the influence of currents and of magnets. "In the presence of the rigid network of β iron the polarized α particles are conceived as catching in the pores of the β structure and immovable in this position, thus resulting in a permanent magnet." Moreover, he supposes the temporary induction and the remanence to be a function of the ratio $\frac{m}{n}$, where m is the percentage of α iron, and n the percentage of β iron in the steel. Let mp and np (Fig. 6) represent the corresponding values; then the maximum induction is proportional to mp, the residual to mr. Further suppose, that the fraction of the maximum induction forming the remanence (r) is proportional to the amount of β iron (n); he then derives the formula

$$r = K\left(m - \frac{m^2}{100}\right) = K\left(x - \frac{x^2}{100}\right)$$

Consequently the remanence is represented by a parabola starting from O upward and meeting the X axis at a point corresponding to 100% α iron.

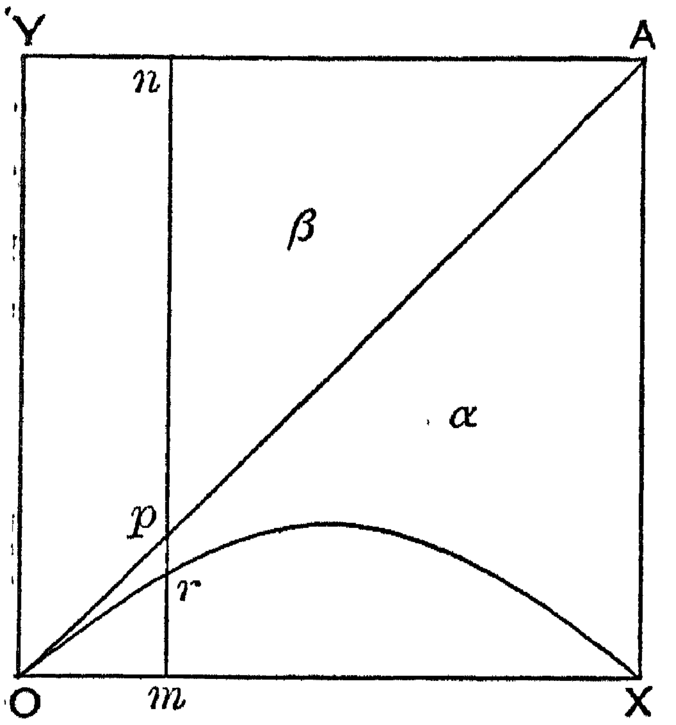

Fig. 6.

Suppose this theory to be correct, then by a change of β iron to α iron the difference between the maximum induction and the remanence increases. My experiments show that this does not take place by reheating the hardened steel. (Compare results represented on Figs. 4 and 5.) On the contrary, the difference becomes smaller. We cannot assume a transformation of α iron to β iron, since the permeability increases decidedly on reheating. On the other hand, the sudden drop of the remanence observed before the point of recalescence is reached, would correspond very well to Osmond's theory, if we suppose a transformation of β to α iron has taken place.

I believe that we have also to take the influence of the carbon compounds into account, which has not been done by Osmond. Let us assume that the reheating has such an influence on the iron in the iron ring and on the carbon compounds as to decrease the relative distance (Fig. 6) between the maximum induction and the remanence, and that the rate of this change decreases, the higher the temperature to which the rings are reheated. Probably the process producing this change, whatever its cause may be, is completed at high temperatures. If besides this there is any other influence present producing a relative drop of the remanence as should be expected from Osmond's theory, when not α iron changes to α iron, this latter effect is masked at the beginning by the effect mentioned first, but it becomes more apparent the higher the temperature and the smaller the change connected with the relative increase of the remanence. Finally at still higher temperatures only the influence of the transformation of non-magnetic iron to magnetic iron remains, the other process being practically completed.

Figs. 4 and 5 show that, while in the iron ring in which there is no β iron, only the first influence can be observed, we have both effects in the steel rings; here the second influence does not appear, until we have almost reached the point of recalescence, and it is the more prominent, the harder the steel or (with Osmond) the more non-magnetic iron the steel contains.

The results of this research may be summarized as follows:

1. The point at which steel becomes magnetically hardened by quenching, lies at different temperatures, according to the amount of carbon contained. It is considerably lower in high carbon steel than in low carbon steel, and corresponds closely to the different temperatures at which recalescence occurs.

2. The higher above the point of recalescence steel is heated before being quenched, the harder it is magnetically.

3. The magnetic hardening produced by quenching is the larger, the higher the percentage of carbon.

4. Reheating has in general a softening effect upon the magnetic properties of hardened steel, *i. e.*, the permeability increases, and is accompanied by an increase of maximum induction and a decrease of the coercive force. But a hardening is noticeable in the low carbon steel after it has been reheated for a short time to 100°. The greatest change in the maximum induction takes place for high carbon steel between 200° and 300°, for low carbon steel between 300° and 450°, beyond which temperature there is hardly any change in the practical limit of saturation. All change taking place in reheating beyond 450° consists in an increase of permeability for small magnetizing forces, *i. e.*, a decrease in the coercive force or hysteresis loss.

5. To produce strong magnets, the hardened steel should first be reheated to 450°.

6. Heating to a high temperature below the point of recalescence and sudden quenching, produces a steel with a very weak retentivity if the value of the magnetizing force has been large; in consequence of which the hysteresis loss in a cycle is greatly decreased. This result may also be obtained, though in a lesser degree, by annealing at a very high temperature.

I am greatly indebted to Mr. L. F. Morehouse, one of my students, for the valuable assistance rendered me in most of the experiments.

Physical Laboratory of the University of Michigan.
March 13th, 1897.

Discussion.

Prof. Henry S. Carhart:—*The Bearing of this Investigation on the Theory of the Constitution of Steel.* The chemical composition of the steel and iron, whose magnetic properties Dr. Guthe has investigated, has been carefully determined. This was done because one of the chief objects in view was the bearing of the magnetic properties of steel and iron on the theory of their composition. The theory of steel has been studied by means of chemical analysis, by its microstructure and by its mechanical and magnetic properties. Dr. Guthe's paper connects the first method and the last two.

The old carbon theory of the hardening properties of steel and its corresponding changes in magnetic properties, has been strongly opposed by the most recent allotropic theory, of which Osmond, of Paris, and Roberts-Austen, of London, are perhaps the most conspicuous supporters. This theory appears to be based on the known chemical and structural changes which the carbon undergoes when the metal is raised to high temperatures, and on the recalescence or retardation points of iron.

Osmond distinguishes three allotropic forms of iron, which he calls α iron, β iron, and γ iron respectively. For the present purpose we need to distinguish between the α and β forms only. The α iron is magnetic, the β form non-magnetic.

The first point of recalescence, or of the retardation which iron exhibits either in the process of heating or of cooling, is from 640° to 690° C. Below this temperature, annealed low carbon iron consists almost entirely of α iron. The point of retardation of the temperature on cooling is about 30° lower than on heating, or the iron exhibits another characteristic form of hysteresis. Iron containing more than about 0.5 per cent. of carbon has only this first point of retardation. It is denoted by A_1.

The second retardation point in low carbon iron, called A_2, occurs at temperatures between 700° and 750° C. Iron having less than 0.5 per cent. carbon and more than 0.25 per cent. exhibits this second point of retardation in addition to the first.

The third point, denoted by A_3, lies between 800° and 850° C. Iron containing less than 0.25 per cent. of carbon has all three points of retardation in heating and in cooling slowly.

When carbon is present in sufficient amount, it has the power of lowering the temperature of both upper points of retardation to that of the first, so that high carbon iron exhibits only the one point.

At these points of retardation, iron changes its allotropic form and these changes are accompanied by changes in the chemical composition of the carbide of iron and its distribution or diffusion through the mass of the iron. Such allotropic changes correspond to a critical change of energy. The passage of iron from one allotropic form to another is attended with evolution or absorption of heat. Professor Roberts-Austen defines allotropy as follows: "Allotropy is a change of internal energy in an element at a critical temperature, unaccompanied by a change of state." When iron is heated to the point A_1, the heating is temporarily arrested with more or less suddenness, and heat is absorbed. On lowering the temperature, the cooling is arrested at a sensibly lower temperature, and heat is evolved.

During these allotropic changes on heating, energy is absorbed at the critical points, as the metal passes from a more stable to a less stable condition. When it cools slowly, the stored energy is given up again at the corresponding points of retardation on the curve of cooling, as the iron reverts to its more stable form. But when steel is suddenly cooled by quenching, Osmond and Howe have shown that there is no point A; or, in other words, the iron exhibits no retardation, and retains the energy absorbed at the retardation points on the curve of heating. It is then assumed that other properties above the critical range of temperature are retained along with the absorbed energy. In general, the heat of combination of quenched steel is appreciably larger than that of the same steel which has not been hardened by quenching. Some anomalies in this branch of the subject, however, await a satisfactory explanation.

Sauveur has recently shown by microscopic examination, that a marked structural change in steel accompanies the allotropic change at each critical point. These "changes of structure," he says, "correspond exactly with the retardations, beginning and ending with them." Within ranges of temperature not containing any critical point, there is no change in the microstructural composition of steel. It is, therefore, not unreasonable to conclude that the energy changes which occur at the retardation points are due to the structural changes themselves. This view is supported by the fact that soft iron ceases to be magnetic, according to Tomlinson, at 950° C., the highest retardation point on heating; low carbon steel at 750° C., the second critical point; and high carbon steel at 650° C., the lowest critical point.

Analogous cases of energy change, accompanying a change in physical state, are that of ice absorbing energy when it passes into a liquid, and sodium sulphate, for example, evolving heat when it passes suddenly from a saturated solution into a mass of crystals.

It remains to be determined whether these critical changes in iron are physically or chemically allotropic, or perhaps both; for if the word compound be used instead of element in the definition of allotropy, it will then include cases of isomerism.

The allotropic theory is founded on these energy changes which carburized iron undergoes when it is heated or cooled; it considers carburized iron as an alloy, and this alloy may be dissolved in the pure iron or ferrite. "The presence of 0.9 per cent. carbon marks a saturation-point of iron by carbon." It is also a fundamental hypothesis in the allotropic theory, that carbon hinders the change of non-magnetic β iron back to the magnetic α form, even during slow cooling. When the hot iron is suddenly quenched, the iron remains largely in the β form, if much carbon is present.

Since α iron is magnetizable, temporary magnetism consists in the setting of the magnetic axis of the α particles more or less completely in the direction of the axis of magnetization. In-so-far as the particles retain this polar arrangement, the magnetism is permanent. Now the inert β iron is supposed to act as a viscid matrix encasing the magnetic particles. It therefore renders it more difficult of magnetization, and for the same reason restrains the α iron particles from returning to their unmagnetized relations to one another. Hence temporary magnetism increases as the relative quantity of α iron increases, while the relative value of the remanence increases with the β iron.

Since carbon is assumed to check the conversion of β iron in cooling to α iron, high carbon iron when hardened is more difficult to magnetize; but on the other hand, when it is once magnetized, it retains it magnetism with greater tenacity than low carbon iron does. In a mixture of α iron and non-α iron, the latter entangles the other and acts as a passive obstacle to the magnetization of iron; it also helps to retain it when once magnetized. Hence the presence of non-magnetic iron is offered as a sufficient explanation of remanence.

In support of the theory that iron undergoes allotropic changes it may be mentioned that iron entirely free from carbon, exhibits the two upper retardation phenomena. The change associated with them is therefore a physical or allotropic one, and is not dependent on carbon. On the contrary, the lowest point of retardation is identified with a change in the carbon; and within limits, the retardation is more pronounced as the percentage of carbon increases.

Again, Beetz found that when pure iron was deposited electrolytically in a thin line on silver parallel to an intense magnetic field, it was permanently magnetized and no more magnetism could be induced in it. Here carbon plays no part in the magnetic phenomena, and besides it is difficult to see how any of the theoretical non-α iron can be present.

Manganese steel presents difficulties for the allotropists. According to the allotropic theory, this steel is hard and non-magnetic on account of the preponderance of β iron. But it is quite possible to give to manganese steel, magnetic properties without diminishing its hardness. Hence it furnishes no proof of the presence of β iron.

Further, an alloy containing 25 per cent. of nickel exhibits remarkable properties. Dr. J. Hopkinson has shown that this alloy is magnetic or non-magnetic, according to the heat treatment it receives. In the non-magnetic form it should therefore be hard, and should contain a very large proportion of iron in the β form. But it is equally soft and can be readily machined in either condition. How then can the allotropic theory explain why manganese steel may become magnetic without losing its hardness, and nickel steel become non-magnetic without losing its softness?[1]

Dr. Guthe has demonstrated that high carbon steel must be heated to a temperature above the lowest retardation point before it is hardened to any considerable extent by quenching, and before it exhibits marked retentivity. The lowest retardation is thus identified with the change in the magnetic properties of steel produced by quenching and hardening.

He has also shown that the remanence is proportionately larger, the higher the steel is heated above the lowest point of retardation. Sudden cooling above A_1 is necessary to enable the iron to retain its magnetism. If it is quenched near A_1, much of the iron may cool below A_1 before it is really chilled. To secure more thorough chilling, it must be quenched from a higher temperature. In terms of the allotropic theory more of the β iron is retained in that form if the temperature is high enough to secure chilling before the iron fails to the point A_1.

With low carbon iron, heating to about 650° and quenching actually reduces the remanence and the coercive force some 25 per cent, as shown by Ring III Ring I. shows that tempering increases not only $\mathfrak{B}_m$, but $\mathfrak{B}_r$ as well. Further, the same ring has both $\mathfrak{B}_m$ and $\mathfrak{B}_r$ reduced by annealing. It is difficult to see in what way the allotropic theory can account for these results.

In contrast with Rings I., Rings III. and IV. show on annealing an increase in the value of the remanence as compared with $\mathfrak{B}_m$.

Again Fig. 4 shows that the remanence, as a function of $\mathfrak{H}$, increases as the process of annealing is carried farther and to higher temperatures. It is difficult to reconcile this fact with the allotropic theory, especially with soft iron rings where the proportion of non-α iron to α iron must be small.

If the allotropic theory is correct, then a transformation of β

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[1] *Trans. Amer, Inst, Mining Engineers*, R. A. Hadfield.

iron to α iron must be accompanied by a decrease in the remanence or residual magnetism, as compared with the maximum induction. This is apparent from an inspection of the diagram in Osmond's theory. Now in the process of annealing β iron reverts to α iron. It will be seen, however, that while in Rings I. and II. of highest carbon, the ratio of $\mathcal{B}_r$ to $\mathcal{B}_m$ decreases as the annealing progresses, the reverse is true with Rings III. and IV. In the step B, however, there is a reduction in the remanence as compared with the maximum induction.

In high carbon steel non-α iron is supposed to revert to α iron at the temperature of the first point of retardation. But Dr. Guthe shows that such steel exhibits a large increase in permeability when it is heated to a temperature between 200° and 300° C. This temperature is much below A_1. Does then non-magnetic iron revert to magnetic iron at this comparatively low temperature? If so, what connection has this magnetic change with the allotropic changes on which the theory is supported?

All existing physical theories of magnetism now recognize that the particles of iron are always magnets. Ewing's beautiful theory and the experiments supporting it are in harmony with the physical phenomena. There is no place in this apparently for non-magnetic iron, and none for the easy passage of iron from the magnetic to the non-magnetic state or the reverse.

Osmond admits that magnetic phenomena come with difficulty into line with the allotropic theory. It is pertinent to raise the inquiry whether some of the facts brought out in Dr. Guthe's paper are not irreconcilable with this theory.

Mr. Paul A. N. Winand:—I would like to remark that the temperature at which the bar has been heated above the critical point, has something to do with the suddenness with which the various parts of the cross-section will cool down past that critical point; because, if we are just above the point to start with, the particles nearer the centre will cool rather slowly at first. They will gradually take a faster rate of cooling, but by the time the rate of cooling has become sufficiently rapid, the temperature of these points has dropped below the critical degree and they fail to become magnetically hard. But if we are pretty well above the critical degree to start with, the whole cross-section will pass pretty suddenly through that degree; and it is perhaps not the fact that the steel was heated at a high temperature, but simply the special circumstance that it was cooled more quickly past the critical degree, which accounts for the difference mentioned in the paper.

My friend Billberg and myself once tried to magnetize bar-magnets by quenching them while they were subjected to the magnetizing force, in order to see whether we could get any better magnets, and there seemed to be a slight difference in favor of this course. We made the measurements only roughly, because we wanted to see if there would be any important gain. The gain did not seem to be sufficient to warrant for the trouble, so we did not try any further in this direction. It may be, however, that some results could be obtained by careful measurements that would throw some light on the subject generally.

Perhaps it would be necessary to employ a very high magnetizing force at the high temperature, as the steel is hardly magnetic at those temperatures. We did not employ a magnetizing force any greater than what seemed to be amply sufficient to magnetize the cold bars to the highest point attainable.

Mention was made by Prof. Carhart of the behavior of a thin film of electrolytically deposited iron which showed permanent magnetism if deposited in a strong field. At high temperatures the material might behave in a similar manner, provided the field be strong enough.

THE CHAIRMAN [Vice-President Pupin]:—I may say that the paper is so exhaustive that it is very difficult for any member present to make up his mind in the course of one evening as to the correlation of facts disclosed in this investigation. There is perhaps no phenomenon that is so complex as the magnetization of iron. I remember that Helmoltz in his lectures at Berlin when I was a student there, whenever he came to discuss the behavior of permanent magnets in a varying electromagnetic field, used to stop and make a very long pause and then finally, at the end of the pause, he would say: "When we come to permanent magnets, then I don't know whether this equation holds true or not." It was a sort of stumbling block in his analysis of the forces which come into play in a varying electromagnetic field. I could not help thinking that in the phenomena which Prof. Carhart described to us, the molecular forces have a great deal to do with the behavior of magnetized iron. Wherever we have a close connection between the changes in the temperature of a substance and the forces the seat of which is in the substance, we may be pretty sure that these forces depend on the molecular state of the substance; because, according to our view of temperature, it is something which depends on the molecular and not on the atomic state of the substance. There is no doubt that these sudden changes in the behavior of the retentive force and the coercive force are caused by a sudden change in the molecular structure. But how close this relation is, it is very difficult to tell. I am rather in favor of the view that these sudden changes in the retentive and coercive force and permeability, are accompanied by an allotropic change in the structure of the substance. Of course, that is only a matter of feeling; and, as I said before, the number of facts brought out by this investigation is so large, that it is very difficult to co-ordinate them and form a consistent physical theory in the course of one evening. We have to be guided more by feeling than by reasoning. I don't know but that such perhaps is the course which we have to pursue in the study of the magnetic literature in general. Take, for instance, Ewing's book and read it; when you get through it you say, "I have got to read it again."

You read it again, and after reading it the second time you have very probably changed your first view, and so the third or fourth time—every time you read it you seem to change your opinion. Lay the book aside, and after about four or five or six months, you feel that your whole knowledge of the facts disclosed in the book is retained in your heart and not in your mind. It becomes a matter of feeling, and not of pure reasoning, and that is the surest sign that the correlation of facts is in a sort of nebulous state, and I think that being in a nebulous state as it is, it is the more interesting. Because when a part of a science is perfectly elaborated and worked out so that there seems but little left to be done, then it is like a garden laid out by a landscape gardener—one likes better to walk in a place where there is something to improve. The investigation described before us this evening invites us into a field which is a very promising one and a very interesting one, although some people seem to think that there is nothing less interesting than a permanent magnet, because a permanent magnet is permanent, and that is all that there is to it. But that is not so, because there is more difference between one permanent magnet and another than there is between any other two things of the same kind. We may congratulate ourselves that the subject has been taken up by so competent hands as those of Professor Carhart and his associates, and I am sure that it is going to remain in good hands and give us much needed information.

MR. NELSON W. PERRY:—I think we are greatly indebted to Dr. Guthe for his paper—probably a little too deep for most of us to discuss off-hand. We are also greatly indebted to Professor Carhart for presenting it in such an admirable manner, and I move that a vote of thanks be tendered to Dr. Guthe for his paper and to Professor Carhart for his kindness in presenting it and for his own remarks upon the subject.

[The motion was carried. Adjourned.]

[COMMUNICATED AFTER ADJOURNMENT BY PROF. ELIHU THOMSON.]

The valuable paper of Dr. Guthe calls attention to the need of accurate knowledge concerning the behavior of steel as a magnetic medium when it has been treated by heating, quenching, cooling and annealing or tempering. Incidentally some of the considerations are shown to apply to those varieties of iron containing such low amounts of carbon as not properly to be called steel, except in relation to the process used in making them. The subject is one of great practical importance and it is only by such experimental data as the paper furnishes that we can advance.

Nearly ten years ago my attention was strongly drawn to the problem of producing permanent magnets for magnetic dampers of meters. There was but little information to be had on the subject, either as to the nature of the steel to be used for the best results, or the methods of treatment, hardening, tempering, or the like to be employed.

This led to the carrying on through several years of thousands of experiments, and the development of methods of rapid measurement of the flux between the poles of the magnets, as well as methods of heating, forming, hardening, tempering, seasoning and testing for permanence. Very many analyses of different steels were also made, with the object of discovering the effect of the differing proportions of carbon, tungsten, silicon, etc. I notice that Dr. Guthe has not included a ring of tungsten steel now almost universally used for magnets, among those subjected to test. In our work we soon found that no steels without tungsten gave such relatively high induction together with other desirable qualities, as steel containing two to three per cent. of tungsten. Amounts up to four or five per cent. of tungsten gave no advantage, while with less than about two per cent. the induction fell off and the metal approached ordinary steels in magnetic qualities.

It was found that the treatment recommended by Barus and Strouhal for seasoning, and referred to by Dr. Guthe, was not sufficient to ensure permanency even where the form of the magnet was, as in our meter magnets, quite favorable to retention of magnetism.

The effect of heating to 100° C. for several hours, caused a loss or diminution of flux which varied with the composition and prior treatment of the steel. Extending the time of the heating to twenty-four hours or more, gave scarcely more effect than an hour or two. The object was, of course, to reduce the flux to that amount which the steel would retain permanently. In the course of this work it was determined that repetitions of the heating to 100° C. after cooling would cause a further loss of magnetism, but at each repetition the percentage became less so that there was at last no discoverable change. A magnet so treated is practically permanent at ordinary temperatures. Whether the effect obtained is due to the removal of that portion of the flux which may be considered as unstable or to a magnetic hardening was unknown, but it would appear from Dr. Guthe's paper that both effects may have been produced, assuming that tungsten steel behaves in the same ways as that of the rings tested by him.

We developed a process of seasoning magnets which consisted in subjecting them after hardening and magnetizing to successive immersions in boiling water and in cold water at intervals of a few minutes; a treatment carried on for a sufficient length of time to ensure stability of the flux density in the air-gap between the poles.

Certain facts alluded to in Dr. Guthe's paper have been known to us for a long time, and were developed in our practice. At one time we arranged to temper our magnets after hardening, by heating them to temperatures just short of those giving the blue oxide coat. This was found to be a matter of difficulty in practice on the large scale, though it undoubtedly increased the induction. It was preferred to obtain a similar result by carefully excluding steels with too high a percentage of carbon, and by hardening the magnets by care in selecting the proper hardening temperature. Thus in fact the same principle was developed in our work as is alluded to by Dr. Guthe, namely, that too high temperatures of hardening give weaker magnets or those in which the steel is magnetically as well as mechanically harder and of too low magnetic susceptibility. It was in fact found that the desired flux could not be retained by such overheated steel when magnetized.

I think that the fact that with ordinary steels the strongest magnets are produced when the hardened steel has been heated to a blue, is well known, and has been practiced for a very long time by magnet makers. The magnets of the old magneto machines were nearly always blued. It has been my practice also for fifteen to twenty years to adopt a similar process in dealing with ordinary steel. After hardening, the brightened steel was carefully heated by a blow-pipe until the middle or neutral region of the magnet (bar or horseshoe) was blued, while the poles were kept of straw color, the one color fading into the other along the bar. A strong magnet is thus made and one which is relatively permanent.

The point made by Dr. Guthe that there is a proper temperature for annealing iron or mild steel in order to secure the greatest freedom from hysteretic loss has also been found to be the case in our practice with iron and steel. The range of temperature for the best effect is found not to be a wide one. Here again there is a widely known mechanical fact which bears upon the point under consideration. It is this, that some steels heated to that temperature which just fails to harden them, are on quenching made very soft. The range of temperature is narrow, but evidently has the bearing upon the recalescence temperature pointed out by Dr. Guthe. This may be observed by heating to redness one end of a bar and quenching it, when it will be found that just back of the hardened end is a very soft portion; noticeably so. It would appear probable that whatever softens the metal mechanically may have a similar effect magnetically.

It would take more time than is at my disposal to touch upon the many other interesting points brought out by Dr. Guthe's paper. I have alluded above to some of the more practical points useful to the constructor.

[COMMUNICATED AFTER ADJOURNMENT, BY J. STANFORD BROWN.]

This paper is very interesting. The chemical composition of steel for magnets, however, is perhaps of more practical importance than might be inferred from the paper, or even from the remarks added by Prof. Thomson.

The use to which magnets are put largely, or you may say entirely, determines the required chemical composition. Steel for permanent magnets will be entirely different from that for electro-magnets. Magnets made to sustain a load are satisfactorily made from a steel which would fail utterly for the controlling magnets of our beautiful Thomson wattmeters, and so on.

The following specification for magnet steel was a few days since submitted to the writer :—

C .75; *W* 4.5 to 5.5; *P* .03; *S* .02; *Si* .10 or less; *Mn* .12 or less.

Such steel is somewhat difficult to make and is consequently expensive, retailing at 40 cents or more per pound, according to quantity. The specification is peculiarly low in *C* for the amount of *W*. With so high *W* the carbon could more usually run from .95 to 1.05.

A highly satisfactory magnet steel for certain uses runs: *C* .65; *Mn* .35; *W* 2.95. On the other hand, for another kind of magnets, *C* .65; *Mn* .60; *W* nil; *Si* .25, and *P* .065 is supplied. Here the high *Si* is noticeable. Sometimes crucible steel is used, and other times a cheap open hearth steel seems to answer. The electrical companies have an enormous amount of data and know thoroughly what they want, but unfortunately they still seem to regard it of too high commercial value to be contributed to the advancement of science and their competitors.

REPORT OF COMMITTEE ON UNITS AND STANDARDS.

To the President and Council of the American Institute of Electrical Engineers.

Gentlemen :—

Your Committee on Units and Standards having carefully considered the communications which you have referred to us, recommend :—

1st. That Hefner-Alteneck Amyl-Acetate Lamps furnished with test certificates from the Physikalisch-Technische Reichsanstalt at Charlottenburg, Berlin, should be temporarily adopted as concrete standards of luminous intensity, or candle power.

2nd. That in measuring the mean horizontal luminous intensity or candle power of an incandescent lamp, a Lummer-Brodhun photometer screen be adopted, and that the incandescent lamp be steadily rotated about a vertical axis through its axis of figure at a uniform speed of approximately two revolutions per second.

Your Committee believe that the adoption of these recommendations would lead in practice to a much greater degree of uniformity in results of measurements of the candle power of incandescent lamps, by different and remote observers than is now usually attainable.

Although incandescent lamps are at present rated by their horizontal candle power, yet, since the only true criterion of the total quantity of light emitted by a lamp is its mean spherical candle-power, we recommend that the rating of lamps should be based upon their mean spherical candle-power so far as is commercially practicable.

Yours respectfully,

A. E. Kennelly, Chairman.
F. B. Crocker,
W. E. Geyer,
G. A Hamilton,
W. D. Weaver.

January 19th, 1897.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, April 28th, 1897.

The 115th meeting of the Institute was held April 21st, at 12 West 31st Street, and was called to order by Vice-President Steinmetz at 8.15 p. m.

The following associate members were elected by the Executive Committee April 28th.

Name.	Address.	Endorsed by
Abbott, Henry	President, Calculagraph Co., 2 Maiden Lane, New York City, residence, 32 So. Clinton Street, East Orange, N. J.	F. A. Pickernell. Stephen D. Field. A. N. Mansfield.
Browne, Sidney Hand	Consulting Electrical Engineer, 809 Equitable Bldg., Baltimore, residence, Ruxton, Md.	Louis Duncan. H. A. Rowland. Hermann S. Hering.
Carter, Henry W.	Attorney and Expert in Patent Causes, Carter & Graves, 810 Reaper Block, Chicago, Ill.	F. S. Hunting. Thomas Duncan. A. L. Searles.
Greenwood, Fred. A.	Secretary California Electric Works, 409 Market St., San Francisco, Cal.	W. F. C. Hasson. Wynn Meredith. F. F. Barbour,
Hoag, Geo. M.	City Electrician, City of Cleveland, 116 City Hall, residence, 3 Dorchester Ave,, Cleveland, O.	M. C. Canfield. Chas. W. Wason. E. P. Roberts.
Kammerer, Jacob A.	General Agent, The Royal Electric Co., Toronto, residence, 97 Macdonell Ave., Toronto, Ont.	Fred. A. Bowman. A. A. Dion. Robert A. Ross.
Lovejoy, D. R.	Assistant in Electrical Engineering, Columbia University, residence, 222 East 49th St., New York. N. Y.	F. B. Crocker. Wm. A. Anthony. Max Osterberg.
Mather, Eugene Holmes	Superintendent and Electrical Engineer, New Haven Street Railway Co., Exchange Building, New Haven, Conn.	Theo. Stebbins. Geo. F. Sever. Charles Hewitt.
Ralston, Louis C.	Graduate Student, Cornell University, 1170 Madison St., Oakland, Cal.	Fredk. Bedell. Edw. L. Nichols. Harris J. Ryan.

SHAW, HOWARD BURTON	Assistant Professor Electrical Engineering, Missouri State University, Columbia, Mo.	E. H. Hall. C. A. Adams. C. L. Cory.
WELLS, DANA CLEMMER	Assistant in Physics, Columbia University, New York, residence, 109 Willow St., Brooklyn, N. Y.	M. I. Pupin. F. B. Crocker, H. C. Parker.

Total 11.

TRANSFERRED FROM ASSOCIATE TO FULL MEMBERSHIP.

Approved by Board of Examiners, March 10th, 1897.

HUMPHREY, HENRY H.	Consulting Engineer, St. Louis, Mo.
RICE, CALVIN WINSOR,	Consulting Electrical Engineer, Winchester, Mass.

Total 2.

The following paper on "The Synchronograph" was then read by Dr. Albert C. Crehore and Lieut. George O. Squier, the discussion of which was deferred to May 18th. The paper was illustrated with lantern slides. The paper was also read at Chicago by Dr. Frederick Bedell.

A Paper presented at the 115th Meeting of the American Institute of Electrical Engineers, New York and Chicago, April 21, 1897.

THE SYNCHRONOGRAPH.

A NEW METHOD OF RAPIDLY TRANSMITTING INTELLIGENCE BY THE ALTERNATING CURRENT.

BY ALBERT CUSHING CREHORE AND GEORGE OWEN SQUIER.

In a general view of the technical history of the art of telegraphy, statistics show that at the present time, more than fifty years since the introduction of the telegraph, nine-tenths of the telegraph business of the world is transmitted by hand, in substantially the same manner as then. From an electrical point of view one naturally asks why it is, that during this period which represents more electrical progress than all time previous, the rapid transmission of intelligence has not made more advance.

It is to experiments upon a new electrical system of rapid intelligence transmission and its possibilities, that your attention and consideration are invited. It is not intended to enter into a discussion here of the physical causes which have limited the speed and efficiency of the telegraph, but to acknowledge the great work of Wheatstone, Hughes, Edison, Delany and others, who have brought rapid telegraphy to its present state of efficiency, and proceed to an explanation of the principles involved in the new system, and an account of the experiments already carried out in developing it. These experiments were conducted at the Electrical Laboratory of the United States Artillery School, Fort Monroe, Va., where the land telegraph and telephone lines were available for the actual trials described.

PRINCIPLES OF THE TRANSMITTER.

It is difficult to treat the subject of transmitters apart from their receivers, as any particular transmitter should be considered in connection with the limitations of its receiving instrument. If we could have a receiver sensitive enough to make a distinct and permanent record of every change in current transmitted over the line, provided the line were so situated as to be free from the disturbing influences induced by external causes, it would be ideal; and the discussion of transmitters would be simplified by reducing the elements to the line and transmitting instrument alone. The qualities of receiving instruments include two principal elements. They all require a certain amount of energy to operate them, and in addition, most of them have inertia in the moving parts. A distinct advance is made, other things being equal, in the receiver which dispenses entirely with the inertia of moving parts. This is accomplished by electrolysis in the chemical receiver of Bain, which has recently reached great perfection in the hands of Mr. Delany. It is also accomplished in the polarizing receiver which was used in experiments described later.

Transmitters for sending intelligence over electrical circuits are, in every case, instruments which operate to change the strength of the current employed in the line. This includes the telephone, in which the current is a succession of waves differing not only in the frequency with which they occur, corresponding to the pitch of the tone, and in the amplitude corresponding to the loudness, but also as to the shape of the waves corresponding to the timbre or quality. The human ear is such a delicate and wonderfully constructed receiver, that it readily translates this complex wave into intelligence. If a physical instrument could be found which would write out in visible form the exact shape of these telephone waves received, the eye might also be educated to translate them. A perfectly trained eye could detect the difference between the same words spoken by different individuals as the ear now does. Even though the waves might be accurately reproduced, the simpler the waves the less the difficulty of translating them.

The inherent distinction between telephony and telegraphy is mainly that, whereas the telephone utilizes both the frequency of the waves and their form, telegraphy relies entirely upon the duration, number, and order of arrangement of these waves, and not their form. The art of telegraphy is practically limited in this respect to three elements, or their combinations, namely, varying the duration of the waves or pulses, the direction of them, their order of arrangement, or the different combinations of these. Considering these elements separately, the first one, using waves of different duration alone for each character upon the line is not at present used. The last method, a combination of variable duration and order of arrangement of waves, comprises the system of Morse and others so universally used, and includes the more rapid system of machine telegraphy due to Wheatstone.

There are reasons why any system using waves of different duration is not as simple as one which uses waves of equal duration, when any arrangement of make-and-break transmitter, using a constant source of electromotive force is employed. Some of the chief of these are found in the electrical properties of the line carrying the currents. The difficulties become apparent only when it is attempted to send these waves at a very rapid rate, which is desirable in machine telegraphy. The current requires time to become established at the receiving end of the line after the electromotive force is introduced at the sending end. The current wave which is sent over the line is a function of the time during which the electromotive force remains applied at the transmitter. There is evidently a practical limit to the shortness of the time which the electromotive force must remain applied, determined by the smallest wave which the receiver is capable of recording.

Suppose on the other hand that the electromotive force has acted long enough for the current at the receiver to reach its steady value, and then the circuit is suddenly broken at the transmitter. A time will elapse before the current in the receiver is reduced to zero. This case is not as simple as the former, because the manner in which the break is made must be considered. A slow break is different from a rapid one, when there is any arc, that is, a spark formed. The whole line has been charged to the limit of the electromotive force used, and must become sufficiently discharged before the next wave can be received. This produces the effect commonly known as "tailing" which means that a signal becomes so drawn out at the receiver that it interferes with the following signal.

If waves of equal duration are used, evidently more of them may be received in a given time, than of any other combination of waves, for the shortest wave may be used which will operate the receiver. With this plan, the effect of "tailing" is reduced. The use of equal waves is adopted by Mr. Delany, who also indicates by the chemical receiver the directions, whether positive or negative, of these equal waves.

The alternating current is at present successfully employed for transmitting considerable amounts of power over long distances, and the whole system is periodically subjected to a regular and uniform succession of waves rising gradually from zero to a maximum, and then gradually decreasing, reversing, and increasing to a negative maximum. Recognizing these facts, it seemed probable that it would constitute a good means for the rapid transmission of intelligence, if the characters of a telegraphic code could be impressed upon such a current without seriously affecting its regular operation. It is to the consideration of a system of rapid transmission of intelligence by the use of the alternating current that we invite your attention.

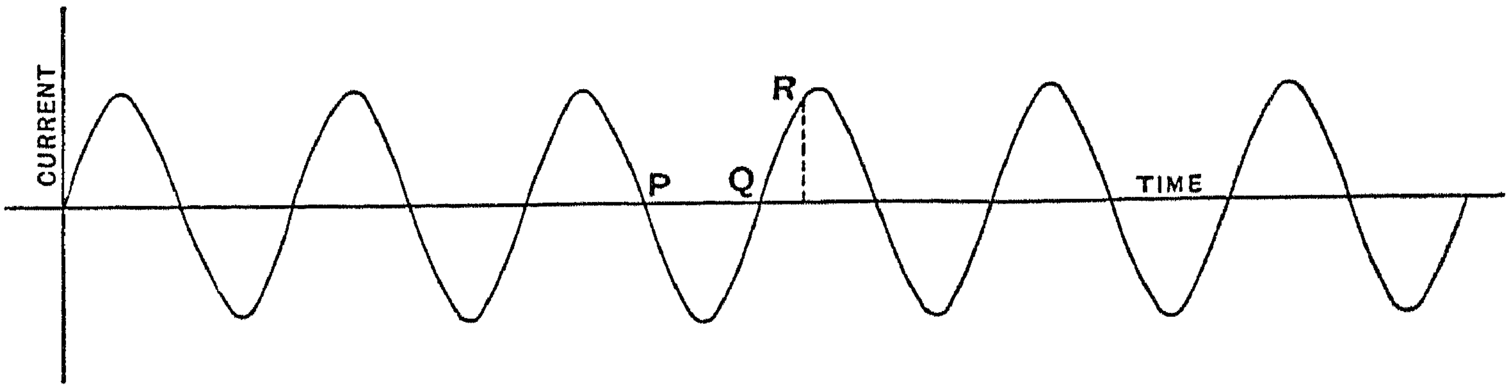

FIG. 1.

Let the sine curve, Fig. 1, represent a regular succession of simple harmonic current waves given to the line by an alternating current generator. If the current passes through a key which may be opened or closed at pleasure, then, provided the key previously closed is opened at a time corresponding to the point P of the wave upon the horizontal axis, it is known that the current which was zero at the instant the key was opened, will remain zero thereafter, in circuits which have resistance and inductance alone. Again, if the key could be closed exactly at a time corresponding to the point Q on the curve also upon the axis, the current will resume its flow undisturbed according to the sine curve. The true current obtained by opening the key at P and closing it at Q

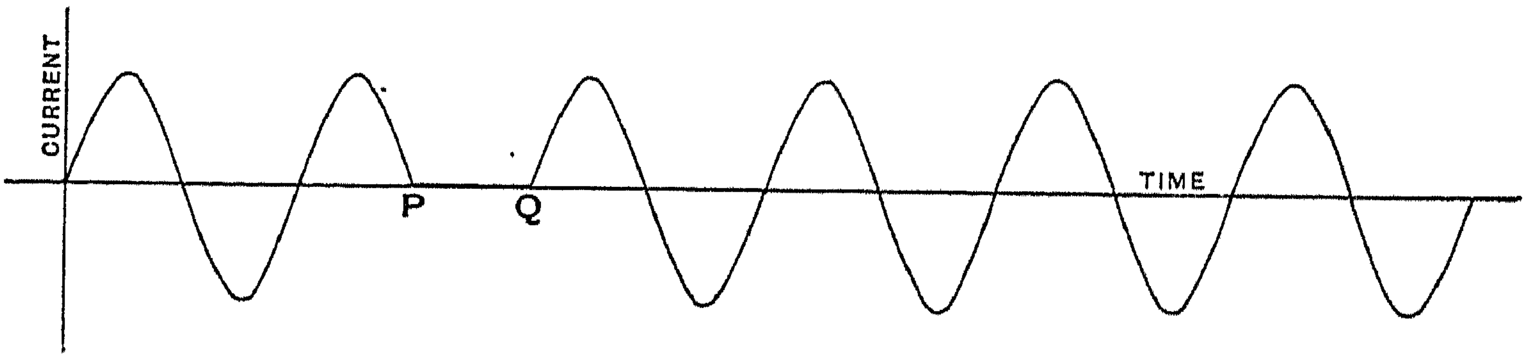

FIG. 2.

is shown in Fig. 2, where the current remains zero between these two points. If the key had been closed at any other point than Q, as at R, the current would not have resumed its flow according to the simple sine wave; but, it can be shown, would follow the heavy curve of Fig. 3, and give a succession of waves alternately smaller and larger than the normal sine wave until after a very few alternations, when it practically coincides with the sine wave. In like manner if the key is opened at some other point than P, when therefore the current is not zero, a spark may be observed at the break, and it requires time for the current to fall to zero.

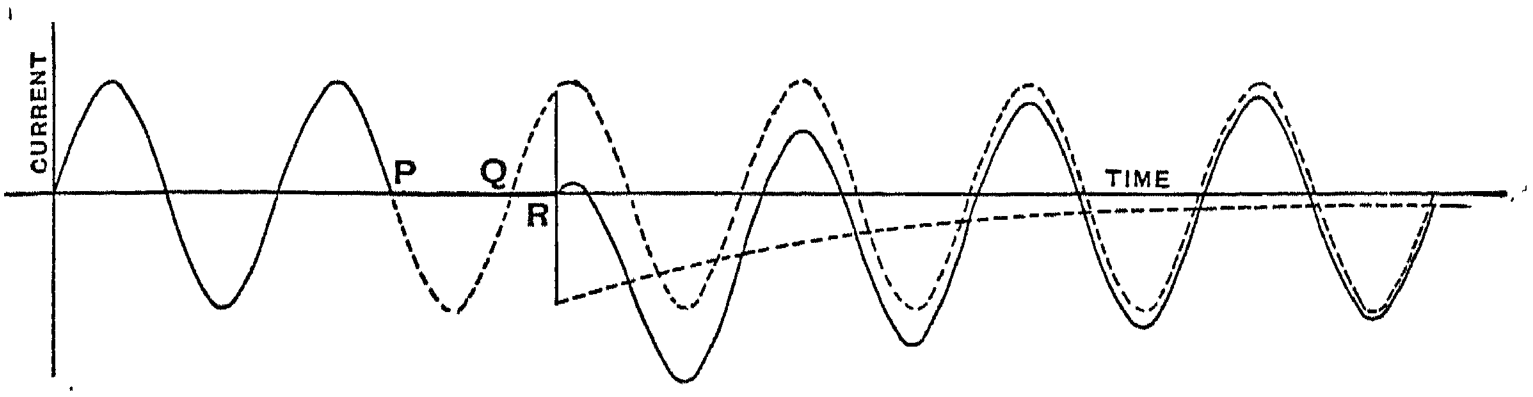

FIG. 3.

Let us consider the advantages of thus operating upon an alternating current. It is evident that the advantages above mentioned of using a system subjected to a perfectly regular alternating electromotive force, and capable if necessary of transmitting considerable amounts of power, is by this method made available. In addition, no spark is made in a transmitter adjusted to break the circuit at the exact times indicated by the curve above, when the current is naturally zero. This makes it possible, if it is found desirable, to use comparatively large electromotive forces and currents on the line, for no matter what the maximum value of the current, it is made and broken by this plan with no sparking. It is also possible to employ waves of high frequency upon the line, the upper limit obtainable from an alternator being probably much higher than can be transmitted over the line.

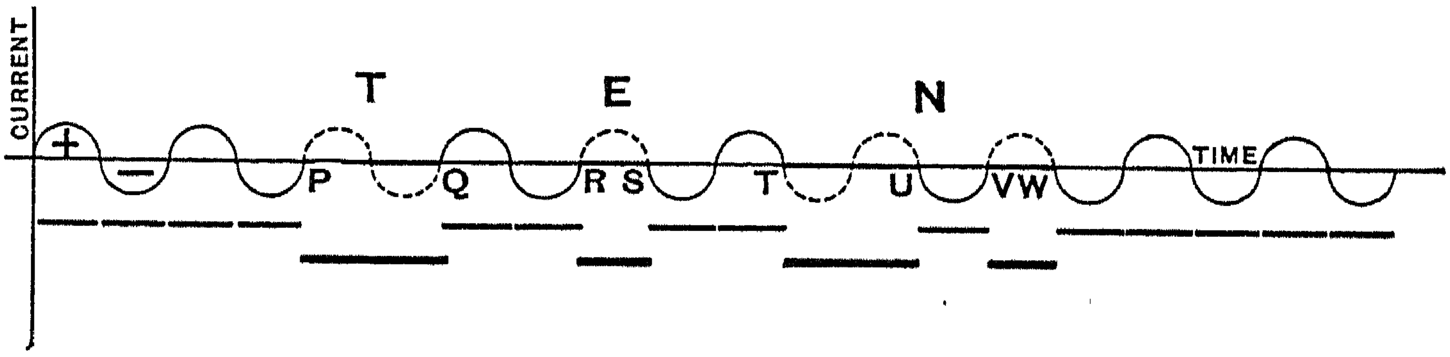

FIG. 4.

If a receiver were used which could reproduce an exact trace of the actual waves sent over the line, it might resemble such a combination as that represented by the heavy curve in Fig. 4. The sine wave continues uninterrupted to the point P when the key is opened, and it is held open for one complete wave-length P Q, when it is again closed for a wave-length Q R; then opened for one-half a wave-length R S; closed for a wave-length S T; opened for a wave-length T U; closed for half a wave-length U V; opened for half a wave-length V W and finally closed. By this plan it is possible to use the ordinary Continental code in telegraphy, a dash being indicated when two successive waves, a positive and a negative one, are omitted by keeping the key open, and a dot meaning where a single half-wave is omitted. The space between parts of a letter, as between the dash and dot of the letter "n" is indicated by the presence of one-half a wave-length, and the space between letters, as between "t" and "e" in the word "ten," by the presence of two half-waves, while the space between words may be represented by the presence of three half-waves, and between sentences of four half-waves or more. The above is a single example, of which there are many, of a method by which the usefulness of so operating upon an alternating current is made apparent, because it shows how these signals may be interpreted by a fixed code. It need not be said that there are other ways easily devised of interpreting the possible combinations of waves which may be sent in accordance with any code, and it is not our present object to present a method which is deemed superior to others, but merely to show that the above plan becomes operative.

A consideration of the time required to send the word "ten" by the above plan shows that it corresponds to the time of eleven half-waves of current. If we suppose that the frequency is an ordinary one used in alternating current work, viz., 140 complete waves per second, the time required to send the word "ten" is .0394 of a second, or, by allowing three additional half-waves for the space between the words, the word "ten" would be sent just 1200 times in one minute. There is no difficulty in using over some lines, a frequency four times as great as that ordinarily used, namely, as high as 560 or even 600 periods per second. This would correspond to speeds of 4800 and 5143 times sending the word "ten" per minute. The limit in each instance is only determined by the particular line used.

Hitherto it has not been pointed out how it is possible to manipulate a key at the high speed mentioned, so as to open and close the circuit hundreds of times per second as desired at the exact instants when the current is naturally zero. Evidently the proper place to manipulate such a current controller where the circuit must be made and broken at distinct points of phase, is at the generator itself, or in connection with any motor running synchronously therewith.

It will be sufficient for purposes of illustration to show by a special example how any single half-wave may thus be controlled at the generator; for obviously any word or sentence may be formed by a repetition of this operation.

In Fig. 5, S represents the shaft of an ordinary 10-pole alternating current generator which drives through the gears M and N, the wheel W. The circumference of this wheel is one continuous conductor presenting a smooth surface for brushes to bear upon. If the periphery of the wheel is divided for example into 40 equal parts, and it is geared to run at one-fourth the speed of the armature, each division thereof corresponds to one semicycle of the electromotive force produced by the generator. Upon the wheel W bear two brushes A and B carried by a brush-holder which is capable of adjustment. These two brushes are connected in series with the line, so that the current which passes in at one brush, is conducted through the wheel to the other brush, and thence to the line. The current used may be obtained from the generator, the shaft of which is represented at S, either before or after it has passed through any number of transformers, since it is the frequency alone with which we are concerned.

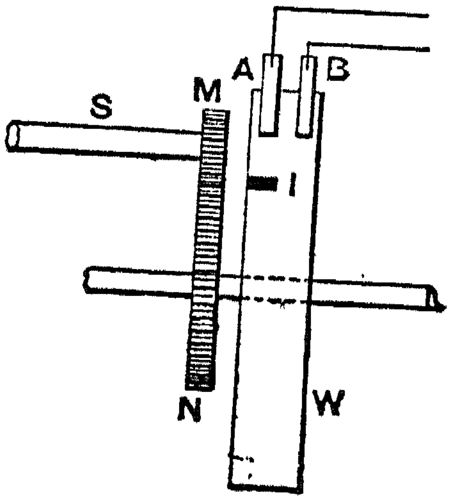

FIG. 5.

The line current is brought to the wheel W to be synchronously operated upon. If both brushes remain continually in contact with the wheel, the current transmitted would have the regular sine form represented in Fig. 1, and for each revolution of the wheel there would be 40 semi-waves or 20 complete waves transmitted. If one-fortieth of the circumference of the wheel is covered by paper or other insulating material as indicated at I Fig. 5, and the brush A adjusted to ride on to and off from this insulation just as the current is changing from one semicycle to the next, that is, changing sign, while the brush B is in continuous engagement with the wheel, the semicycle represented by the section covered will be suppressed, and without any sparking, even if the potential used is high. In practice, the brush A is easily adjusted to this point by moving it slightly, backward or forward around the circumference of the wheel until the sparking ceases. This adjustment once made, the brush is fixed in position and so remains. In each succeeding revolution of the wheel, this cycle of operations is exactly repeated, and the current sent over the line would resemble that shown in Fig. 2, having every fortieth semicycle omitted. It is only necessary to cover other similar sections of the circumference of the wheel in a predetermined order according to a code, to transmit intelligence over the line. The above illustration of the operation of a transmitter on this principle is given for simplicity only, and is evidently far from a practical form of transmitter.

The wheel W in the above example, may have different speeds with respect to the generator shaft, the essential condition being that its circumference shall contain some integer number of a unit, which is the arc upon the circumference of the wheel if geared to the armature, that a point fixed with respect to the field would describe upon it during one semi-period of the current. This wheel therefore might be connected to any shaft which runs in synchronism with that of the generator, as for instance that of a synchronous motor if the power were obtained from a distance.

Instead of using insulating papers situated upon a single circumference of the wheel, two or more similar lines may be used either upon different circumferences of the same wheel or upon different wheels, and separate brushes ride upon the different circumferences. The same frequencies of current may be employed to operate all lines of brushes, or currents having different frequencies may be employed upon the separate circuits, all of which use the same line for transmission. These arrangements make it possible either to send different messages simultaneously over the same line employing a single cycle as the unit, or to send a message employing different frequencies to represent the different characters of a code, or many combinations of these.

The employment of alternating waves of different frequencies upon the same line by the method shown, does not have the same objections which exist when a constant electromotive force is used. Since the circuit is by this system always interrupted when the current is naturally zero, the frequency employed is within certain limits a matter of indifference as the line is in the same condition whether a long or a short wave is used.

It is seen that by this simple method of operating upon the alternating current, according to the above principles, there is complete control of the individual semi-waves of the current, which may be changing direction thousands of times in a second, far beyond the range of possible manipulation by hand. In other words it is easy to obtain a record of any pre-selected order or succession of semi-waves desired. It is evident that it is as important to be able to control the semi-waves retained, as it is those suppressed, since they are of equal value in interpretation. Furthermore there is great utility in being able to control *each single semi-wave* of the current, for this permits the maximum speed of transmission of signals with a given frequency.

A transmitter which operates upon the current at intervals comparable with the duration of a semi-wave, but which does *not* act in synchronism with the current, would necessarily make and break the circuit at times when the current is not naturally zero. If this were done there would not only be sparking, but in addition, the current would be interfered with in such a manner as to make it probable that the record received could not be interpreted; for the current at each make would follow such a curve as that shown in Fig. 3.

PRINCIPLES OF RECEIVERS.

As used throughout this paper, the term "receiver" will be understood to mean that mechanism which uses the energy transmitted over an electric circuit, and transforms it so as to make a permanent record which may be translated into intelligence. The term receiver is here restricted to mean instruments which make a permanent record, since this is a necessary condition for the rapid transmission of intelligence, with which we are at present concerned. All receivers require a certain amount of power to operate them, and the power required affords one basis for their classification.

Another method divides receivers into two classes, those which have inertia in the moving parts and those which have none· There is no fundamental reason why any one of these general classes should contain all of the most rapid receivers. Any of the above classes might include receivers which are very rapid. If, for instance, a receiver has inertia in the moving parts, for rapidity the amount of inertia should be small, and its natural period high, or a large amount of energy would be required to operate it. If a receiver has no inertia in the recording mechanism, then the possible rapidity is limited by the power supplied.

In deciding upon the relative merits of receivers from the point of view of rapidity, the cost of the power required offers no reason why considerable amounts of power should not be transmitted over certain land lines for purposes of telegraphy. Using a receiver which possesses much inertia in its moving parts, it does not follow that even though considerable energy reaches the receiver over the line, that it will be rapid in its action.

The Wheatstone receiver may be taken as representative of a type of receivers possessing inertia in the moving parts, which has come into successful operation. The record is made in this instrument by a small wheel which vibrates back and forth between an ink surface and the recording tape. The energy which is essential, is that required to move this little wheel and the parts connected with it back and forth. Although considerable energy may possibly be sent over the line and be expended in the instrument, it seems impossible to concentrate more than a certain part of it upon the moving mechanism. This suggests two methods of improving the speed of the system; either to increase the power received by the moving parts, or diminish their moment of inertia. One factor which limits the Wheatstone type of receiver is that the moving parts are required to do the work of making the record. This is not a necessity, since light may be employed as the agent to make the record under the control of the moving parts, as is evidently accomplished in a form of galvanometer having a very minute needle with mirror attached, the slightest motion of which is greatly magnified by the reflected beam of light.

As a type of instrument having no inertia in the recording mechanism, may be mentioned the various forms of chemical receivers acting by electrolysis. This type of receivers possesses many advantages, perhaps chief among which is the fact that a large part of the energy received is brought directly to bear upon making the record. Another feature is the simplicity of the essential mechanism involved, as no intermediate steps are employed after the impulse is received from the line before the record is made. These qualities alone imply rapidity, and this receiver is one of the most rapid known. The limit of rapidity with this receiver is the power received from the line. If the potential between the terminals of the receiver is increased, the time required to make a given record is correspondingly reduced. The use of the alternating current permits of greater potentials being realized in the receiver with less disturbing influence from the line than would be the case if a constant direct electromotive force was employed.

A new type of receiver having no inertia in the recording mechanism was used in developing the transmitter described in these experiments. This instrument has already proved of value as a chronograph for the measurement of minute intervals of time, and for the study of any kind of variable electric currents. Although its application as a practical telegraph receiver is not at present advocated, yet the realization of a *massless* receiver upon different lines merits description. This receiver is based upon Faraday's discovery of a direct relation between light and electricity.

This discovery was, that if a beam of polarized light is passed through some substance in the direction of the lines of magnetization within that substance, there is a rotation of the plane of polarization in a direction which is the same as the direction of the current required to produce such a magnetic field. The direction of rotation is unaltered, therefore, whether the light beam advances in the same or in the opposite direction to the magnetization, so that a beam reflected back and forth through the substance several times, has its rotation increased by equal amounts each time. If the direction of the ray of light is at right angles to the lines of magnetization, there is no rotation produced. The amount of this rotation has been investigated by Verdet, who announced laws by which it may be expressed. They are summed up in the following statement:

"The rotation of the plane of polarization for monochromatic "light is in any given substance proportional to the difference in "magnetic potential between the points of entrance and emergence "of the ray"; that is, it is equal to a constant times this difference of potential and is expressed by the formula

$$\theta = v\ V,$$

where θ = angle of rotation, V = difference in magnetic potential, and v for a given wave-length is constant in any one substance and is known as Verdet's constant.

The following example will make more evident the application of Faraday's discovery to this receiver. Admit a beam of ordinary light through a small aperture into a dark room and let it fall upon a white screen. Suppose that the aperture which admits the beam is provided with a shutter which may be opened or closed at will. We have in this simple arrangement all the essentials of a transmitter and receiver of intelligence. A person opening and closing the shutter might communicate with a second person observing the screen, which would become light and dark at intervals in accordance with a pre-arranged code. Substitute for the first person in direct control of the shutter an electromagnetic device, operated from any desired distance through an electric circuit, and the effect upon the screen is the same as before. For rapid transmission it would be necessary to substitute a mechanical transmitter which would operate faster than a person can send by hand. There would be no particular difficulty in thus moving the shutter more rapidly than any observer could read from the screen. It then becomes necessary to make a permanent record, which may be accomplished by substituting for the screen a self-recording surface having a relative motion across the beam. This is afforded by using any surface sufficiently sensitive to light, many varieties of which are available. In fact a surface is available which is so sensitive that it will record much faster than the *material shutter* can be moved back and forth so as to open and close the aperture.

The next step in increasing the speed, provided the limits of the transmitter have not already been reached, is to secure a more rapid shutter. It was with this object in view, to obtain a *massless shutter* that Faraday's discovery is used. Instead of passing the light directly through the aperture, it is first passed through a Nicol prism in order to obtain a beam of plane polarized light, or it may be polarized in any other suitable manner. Suppose that a second Nicol prism like the first is placed in the path of the polarized beam. If the second prism known as the "analyzer" is turned so that its plane is perpendicular to that of the first prism known as the "polarizer," all the vibrations not sorted out by the polarizer will be by the analyzer. In this position when the planes are perpendicular to each other, the prisms are said to be "crossed," and an observer looking through the analyzer finds the light totally extinguished as though a shutter interrupted the beam. By turning the analyzer ever so little from the crossed position, light passes through it, and its intensity increases until the planes of the prisms are parallel, and if one of the prisms is rotated, there will be darkness twice every revolution. In order to accomplish the same end that is obtained by rotating the analyzer without actually doing so, the following plan is adopted: Between the polarizer and the analyzer is placed a transparent medium which can rotate the plane of polarization of the light, subject to the control of an electric current, without moving any material thing. The medium used in this receiver is liquid carbon bisulphide contained in a glass tube with plane glass ends. There are many other substances which will answer the purpose, some better than others. This was selected because it is very clear and colorless, and possesses the necessary rotatory property to a considerable extent. It only possesses this property, however, when situated in a magnetic field of force, and the rotatory power is proportional to the intensity of the magnetic field. To produce a magnetic field in the carbon bisulphide, a coil of wire in series with the line from the transmitter is wound around the glass tube. When the current ceases, the carbon bisulphide instantly loses its rotatory power. The operation is as follows: First the polarizer and analyzer are permanently set in the crossed position, so that no light emerges from the analyzer. A current is sent through the coil around the tube. The plane of polarization is immediately rotated. This is equivalent to rotating the polarizer through a certain angle, and hence light now emerges from the analyzer. Interrupt the current, the medium loses its rotatory power, and there is again complete darkness. The arrangement makes an effectual shutter for the beam without moving any mass of matter.

This illustrates how Faraday's discovery may be utilized to replace the electromagnetic shutter in the above example by a massless shutter, which enables the current waves sent over the line to be recorded upon the sensitive surface without moving any material thing. An advantage of this receiver is that the speed is not limited by the receiver but only by the natural properties of the line or of the transmitter. Used in connection with the transmitter already described, the real limit is found to be in the line itself.

An analysis of this receiver shows that the energy received over the line is not used directly in making the record, but the agent which makes the record is the beam of light which derives its energy from a local source. The energy received from the line merely controls this local energy which may have considerable power behind it. This controlling phenomenon is one of the few known cases where electricity acts directly upon light. The mechanism by which this action is effected is not at present known, and any experimental evidence upon it would increase our knowledge of the connection between ether and ordinary matter, as well as the constitution of matter itself. The use of this direct influence of electricity on light makes the speed of transmission through the receiver comparable with the velocities of these agents.

DESCRIPTION OF THE TRANSMITTER USED.

In these experiments, the operation upon the alternating current according to the principles already stated, was accomplished by means of a prepared perforated paper tape, which was caused to move by the generator itself. A view of this tape, showing a method of operating upon the current is given in Fig. 6.

The line current is brought through the wires W W to two brushes B B′ not shown in the view, held by the adjustable support S. The plan of the brushes is shown in Fig. 7. One brush B bears upon the tape from above, and the other brush B′ bears from below immediately opposite the other brush so that they will meet through the perforations in the transmitting tape T. When the brushes meet through the perforations in the tape, the line circuit is closed, and when paper passes between them, separating the brushes, the line circuit is broken.

It is so arranged that the brushes pass off from, and on to the paper, thus making and breaking the circuit, at the instant corresponding to the points in the current wave, Fig. 1, when the alternating current is naturally zero. The tape T passes over a wheel P geared to the generator shaft, so that for one revolution of the armature, the tape advances a fixed distance. If the generator has ten poles, this fixed distance on the tape corresponds to five complete waves or ten alternations or semi-cycles of the generator current. One-tenth of this fixed distance corresponds to one alternation or semi-cycle of the current, and may be taken as the unit of distance in perforating the tape. If therefore a hole is made in the tape equal in length to this unit, and the brushes B and B′ happen to pass off from the paper so as to meet through the hole at the instant the current is naturally zero, then they will pass on to the paper again, breaking the circuit at the next following instant when the current is also naturally zero, since the length of the hole corresponds to one semi-cycle of the current.

Suppose that a succession of these unit holes is made, the tape between the holes being also of unit length, then the circuit will be made and broken as by the first hole at the points of zero current. In practice it would probably not happen that the brushes were at first so situated as to pass off from and on to the paper at the instant the current is zero. In this case a succession of sparks appears, one each time the brushes pass on to the tape, and by moving the brushes along the tape it will be observed that this spark either increases or decreases in intensity, according to the direction moved; but at regular intervals, equal to the unit mentioned above, it disappears. This position of the brushes for no sparking is easily found by trial, and once obtained remains fixed. By this simple practical operation which experience shows requires but a moment to accomplish, the essential condition of synchronously operating upon the current in the manner described is secured. The brushes once adjusted always so remain, and since there is no sparking, it is possible to use high electromotive forces upon the line without injurious effect upon the brushes and tape. It is also plain that this method of operating upon the current is not affected by the speed of the generator, since the transmitting device is always in synchronism with the generator,

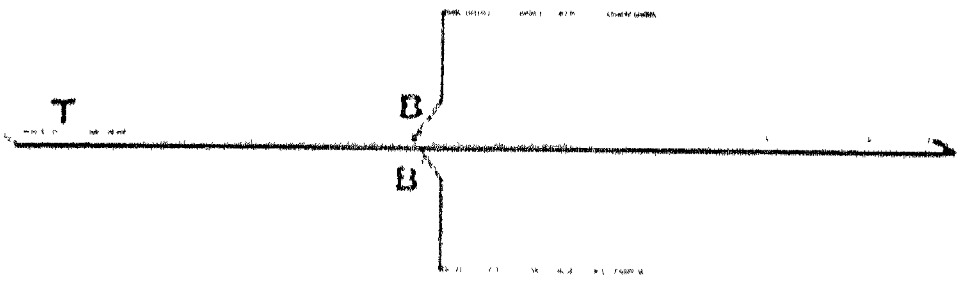

FIG. 7.

whatever the speed. The speed of the generator, and consequently the rate of sending, as far as the transmitter is concerned, can be varied at pleasure between wide limits, without any effect upon the synchronous operation described.

An example, giving the data from an early experiment, will illustrate how this is accomplished. The generator was a Fort Wayne 10-pole alternator giving a potential at its terminals of 1,000 volts. This was transformed to about 300 volts, being convenient to handle, and sufficiently high for the purpose. The end of the shaft E, Fig. 6, of the generator carries a small pinion, which engages the gearing G, and revolves the wheel P once in every 18.4 revolutions of the armature. This makes the $\frac{1}{184}$ part of the circumference of the wheel P correspond to one semi-cycle of the current. The circumference of the wheel was about 100 cms., and the length of a unit, therefore, $\frac{1}{184}$ of this, or .54 cms.

For convenience, a tape made of ordinary paper, had its two ends joined so as to make a continuous belt, which made it possible to use it repeatedly. The tape passed from the large wheel P to the loose pulley Q mounted upon a base-board A, and under the guiding pulley attached to the support S which controlled the tape, immediately before passing the brushes B B′.

In preparing the tape, the Continental code was employed as described, the omission of two half-waves meaning a dash, and one half-wave a dot. Having obtained the length of a unit on the wheel, the tape is first divided into these equal units, and then the proper units are cut out to form a message. The units which are not cut out form the dots and dashes. To use a continuous tape it is necessary for its length to be some exact multiple of the unit, in order that it may start on the second revolution exactly as it did the first.

The generator current of high potential passed directly through the primary of a transformer, and the secondary was used as the source of electromotive force for the line. This secondary circuit which includes the line was brought to the transmitter to be operated upon as described.

A diagram of the electric circuits as employed in this experiment is shown in Fig. 8, where A represents the alternator, T the transformer, B the brush bearing upon the transmitting wheel W, and L the line. Another diagram illustrating how the method may be used with currents of the same or different frequencies,

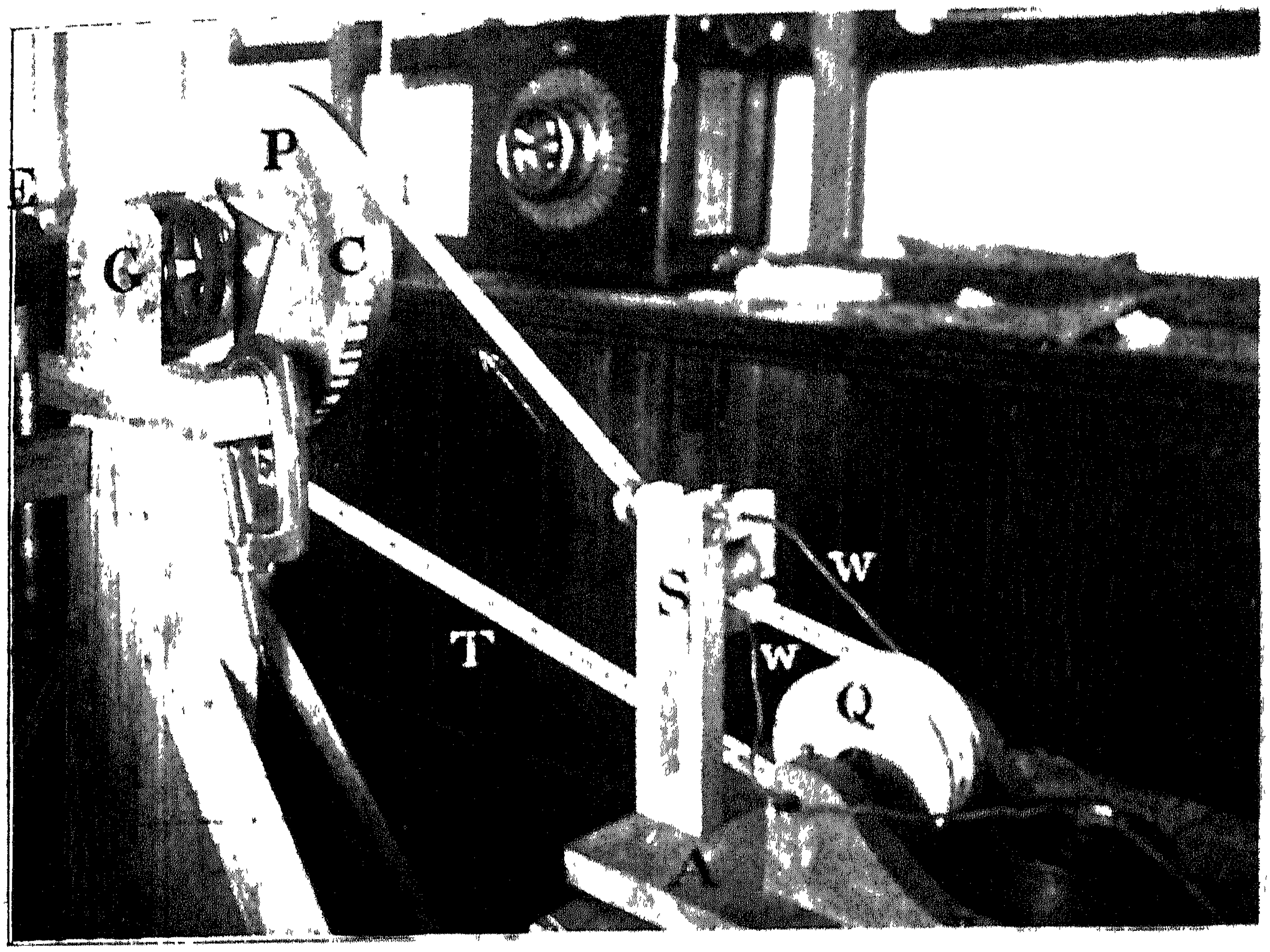

FIG. 6.

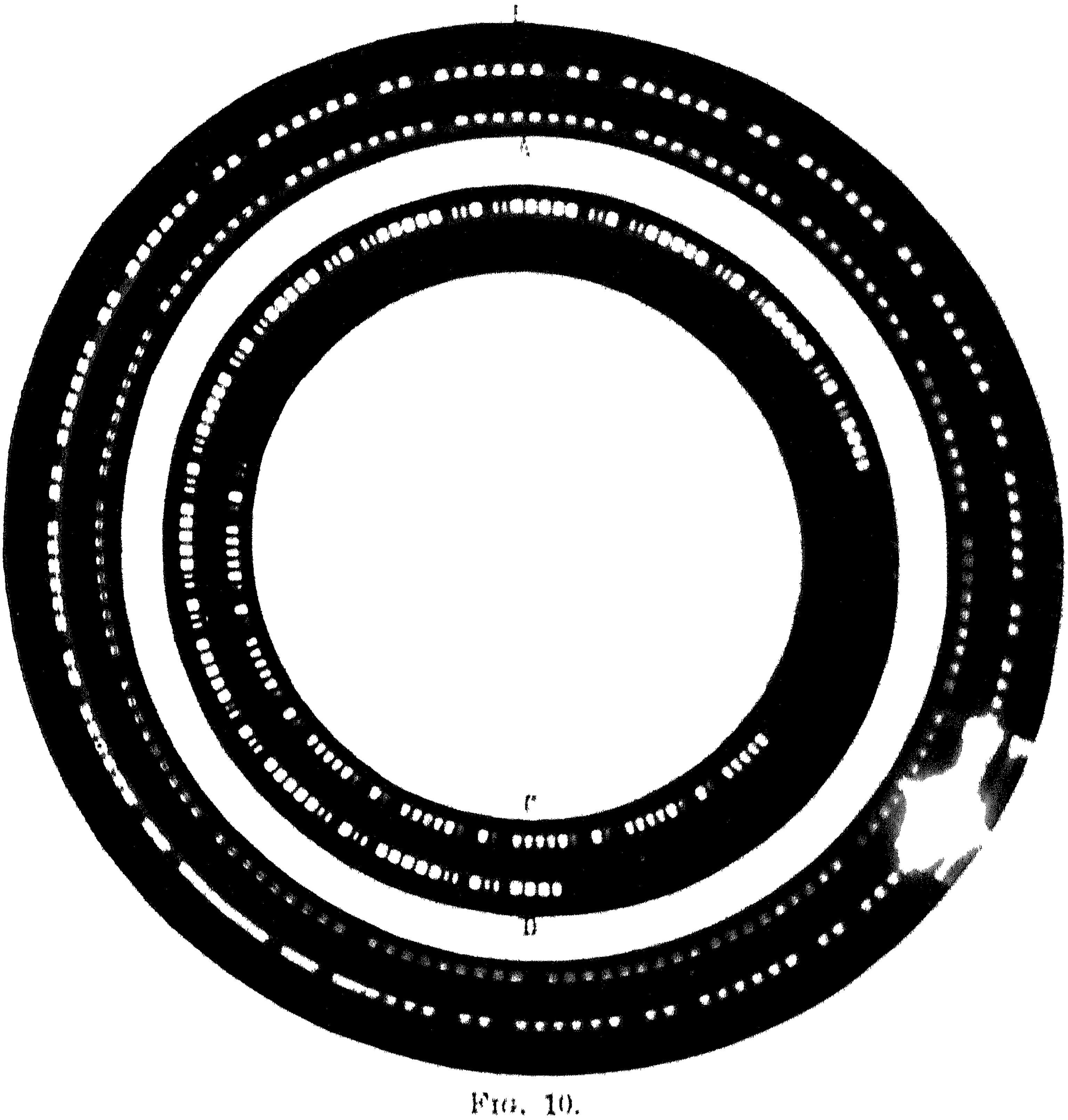

FIG. 10.

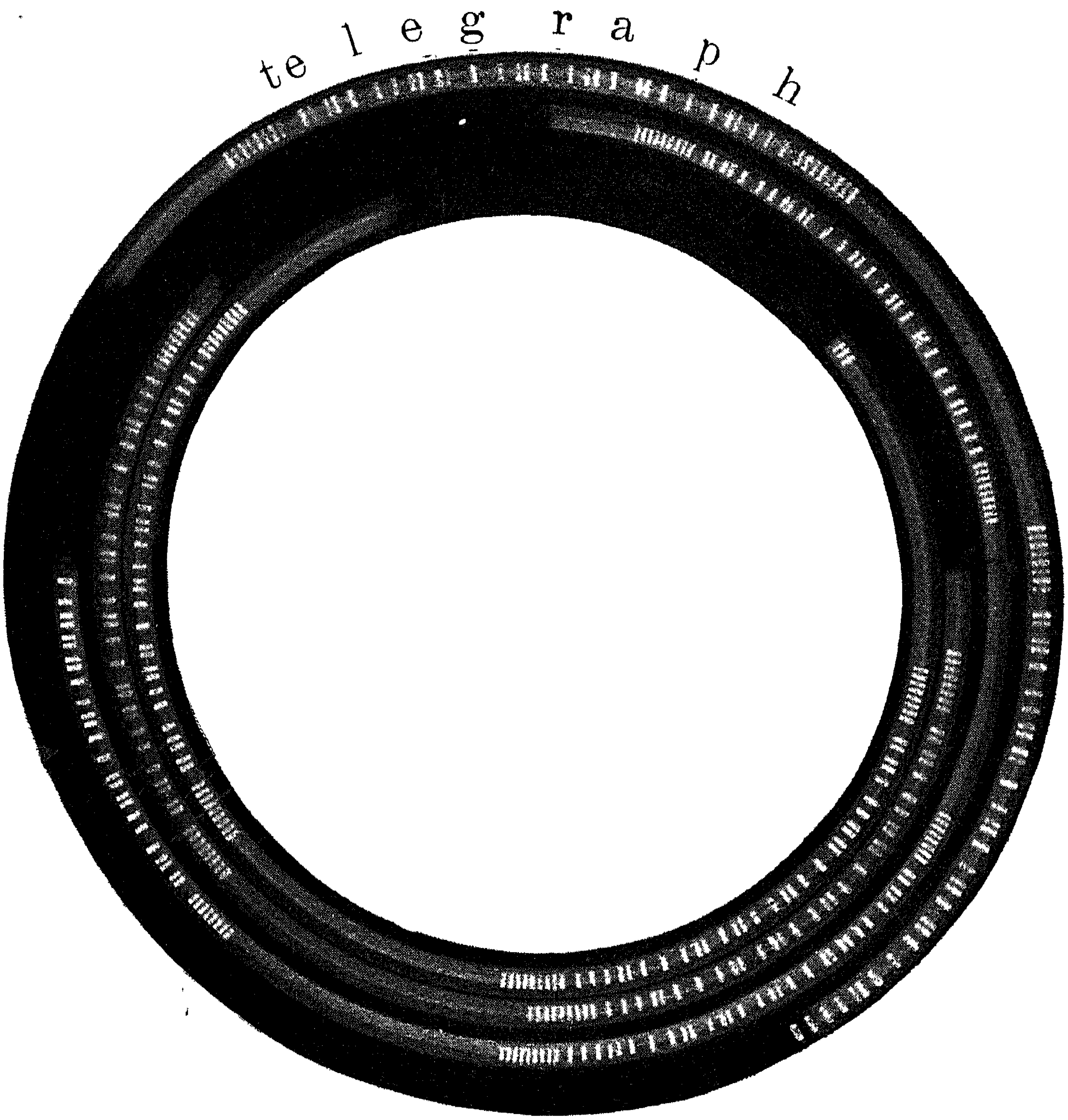

FIG. 11.

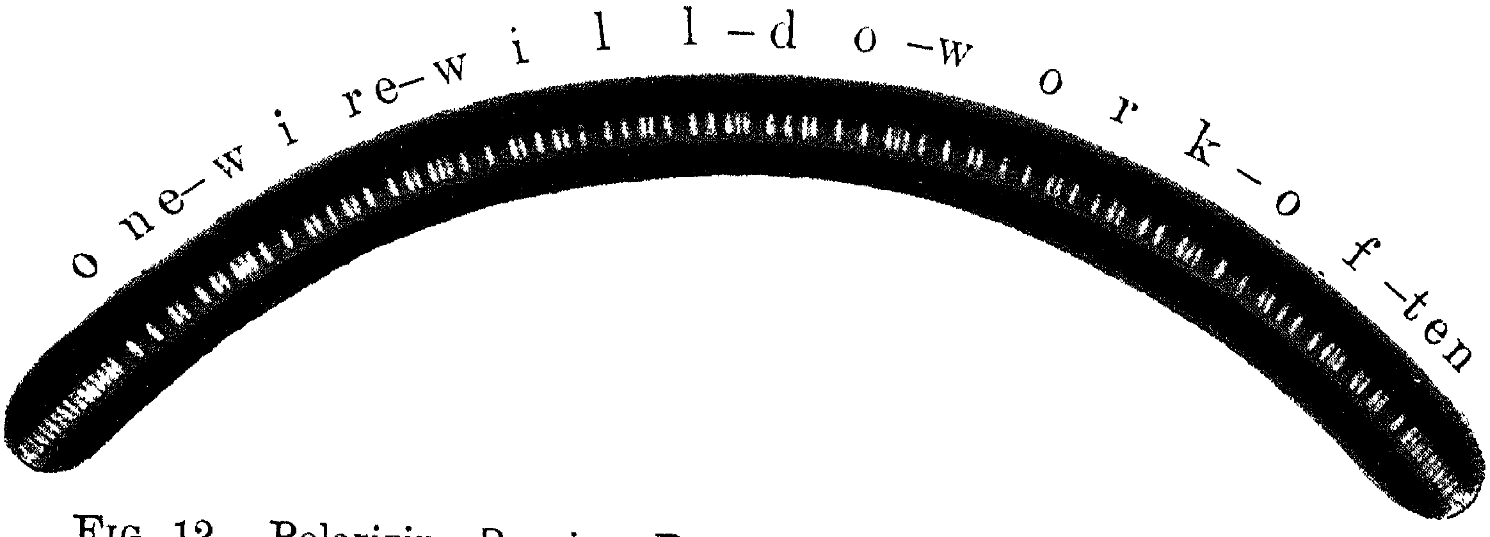

FIG. 12. Polarizing Receiver Record. Message sent at Fort Monroe, Va., Aug. 10, 1896, at the rate of about 1,200 words per minute. This particular message sent in one-half a second. The number of "dots" per second is 337. Continental Code is used.

is given in Fig. 9, where several generators A_1, A_2, A_3, etc., are represented upon the same shaft, and each is connected to a separate brush B_1, B_2, B_3, etc., bearing upon the wheels W_1, W_2, W_3, etc., upon a common shaft and connected to the line. By placing the insulating papers in the proper positions upon the wheels, it becomes possible to transmit in succession, first a current of one frequency and then of another.

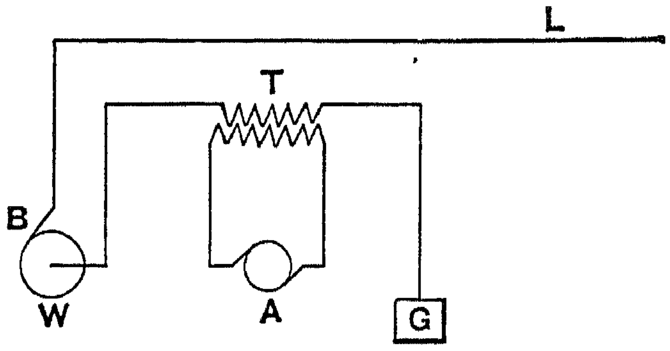

FIG. 8.

If any error is made in laying off the units upon the tape, or if the length of the tape changes in any way after they are accurately laid off, the effect of this error is cumulative from period to period, and although at any particular time the tape might be in phase, sometime later it would not be so, and sparking would occur. This would also be the case if there were any slipping of the tape around the wheel P. To overcome these difficulties it is only necessary to have holes punched at regular intervals in the tape which engage in pins at corresponding intervals on a wheel made to receive it.

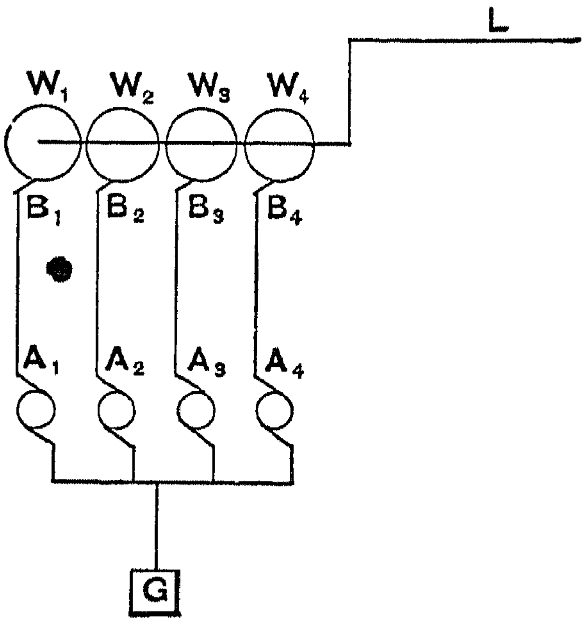

FIG. 9.

A simple experimental method which does away with the necessity of making pins to feed the tape, is to glue strips of thin paper, seen at C, Fig. 6, having lengths corresponding to the paper intervals of the tape, that is, one unit for a dot and two units for a dash, upon the circumference of the wheel P, which has a smooth polished metal surface. One brush is continually in contact with the wheel, and the other rides on to and off from these paper strips, making and breaking the circuit at the zero phase of the current. The length of message permitted, is limited by the number of units in the circumference of the wheel, which in the example taken was 184.

Instead of using any gearing, as in the example given, to reduce the speed of revolution of the wheel P, the tape might be run directly from a small wheel upon the armature shaft. The unit on this small wheel is one-tenth of its circumference, if there are ten poles to the generator, so that any message sent by fastening papers upon this wheel would be limited to ten semi-cycles. If a single unit of this small wheel is covered by paper, and the brush adjusted for no sparking, one semi-cycle in every ten will be omitted. A record obtained in this case with the polarizing receiver is shown in the circle at A, Fig. 10, in which each light spot corresponds to one semi-cycle of current, and it is seen that one in every ten is omitted. The record in the circle B of the same figure was obtained by using two units of paper on the same wheel, having two units between them, and shows that two semi-cycles are omitted in every ten.

Records obtained by the use of paper fastened upon the large wheel P, Fig. 6, are shown in Fig. 11, where it is seen that the word "telegraph" was transmitted. A record obtained by the use of tape is shown in Fig. 12, where the sentence "one wire will do work of ten" was transmitted on August 10, 1896. This message was sent at the rate of 337 semi-cycles of current per second, thus requiring about half a second altogether.

Since the speed of transmission depends upon the frequency of the alternating current, the limit of speed is determined by the particular alternator used. In the above example the alternator available was designed to run at a speed of about 1600 revolutions of the armature per minute, corresponding to a frequency of 133, or 266 alternations per second. To increase the speed of transmission, this alternator was run as high as 2400 revolutions per minute, beyond which it was thought dangerous to go. This corresponds to a frequency of about 200 complete cycles or 400 alternations per second. Through the kindness of Dr. M. I. Pupin of Columbia College, a special high-frequency alternator

ras loaned for the purpose of testing this system at higher speeds f transmission. This alternator, shown in Fig. 13, is in fact four lternators upon the same shaft, having 18, 22, 26, and 30 poles espectively. To obtain the highest speed, the 30-pole machine ras used, and the transmitting wheel geared to the shaft as with ie ten pole alternator. The speed of armature used was 2180 evolutions per minute, corresponding to 1090 semi-cycles per econd, or 65,400 per minute, or a frequency of 545. No difficulty ras experienced in sending and recording messages at this rapid ite which corresponds to between three and four thousand words er minute.

The Polarizing Receiver.

The statment of the general principles employed in this receiver as previously been given, and it remains to describe the actual orm. This instrument was designed for a military chronograph measure the velocity of projectiles, and is known as the Polar- ing Photo-Chronograph[1]. A view of this is shown in Fig. 14.

Without giving a complete description of the instrument, which ay be found in the reference cited, it will suffice to describe its sential elements. A sensitive photographic plate 12 x 12 inches uare is carried in a metal plate holder, which revolves in the heel W driven by the motor M. A powerful beam of light from e arc lamp, A, situated upon an inverted T-rail, O', serving as an ptical bench, is condensed by the lens L, and passes through the larizer P, a Nicol prism, thence through the glass tube T, con- ining liquid carbon bisulphide, and surrounded by a coil of wire, rough the analyzer A, a second Nicol prism. The light received rough the analyzer is finally passed through a second lens L' to cus the beam upon the horizontal radial-slit in front of the mov- g sensitive plate. In its operation, the analyzer A is rotated ntil the light is completely extinguished, when no current is pass- g around the tube T. The coil upon the tube is in circuit with e line from the transmitter, and the closing of the circuit at the ansmitter thus sends a current around the tube, and light im- ediately appears upon the camera slit. This is accomplished in- antly upon closing the circuit, without involving the motion of ny material thing. Upon breaking the circuit the light immediately disappears, and by observing the light come and go, it is easy to read with the eye as rapidly as can be sent by hand. To produce a permanent record it is only necessary to rotate the photographic plate in the wheel w. The time required by the photographic plate to make a clear record, depends largely upon the intensity of the light; but the intensity of light which it is practicable to obtain allows the time of exposure to be much shorter than is required for the purpose of a telegraph receiver. For instance, suppose the width of slit is one millimetre at a distance of 150 millimetres from the centre of revolution, and the plate rotates 1000 times per minute, the velocity of a point on the plate is 1570.8 cms. per second, and the exposure is therefore about .000063 second; for the point crosses the millimetre slit in this time. The above figures are those actually used with the chronograph in measuring the velocity of projectiles inside the bore of a gun and the records obtained are perfectly clear. The rapidity of this receiver is illustrated by stating that as many as seven observations upon a projectile inside the bore of a U. S. 3.2-inch breech-loading field rifle have been recorded in the first 57 centimetres (1 foot 10½ inches) of its travel, and observations as near together as 3.8 cms. (1½ inches) have been obtained. These correspond in time to intervals less than a thousandth of a second, or they bear about the same relation to a second, as a second does to a third of an hour.

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[1] "The New Polarizing Photo-Chronograph," Crehore and Squier. John iley & Sons, New York, 1897. Chapman and Hall Ltd., London.

In chronography as applied to gunnery, since the agent which operates upon the transmitter circuit is the projectile itself making and breaking the circuit by passing through screens, evidently if the screens are properly placed according to a code, a message could be transmitted to the receiver by a projectile in its flight.

THE CHEMICAL RECEIVER.

In a practical form of receiver, it is an advantage to have the messages received in such form that they are ready for immediate use, and this is the case with the chemical receiver to which reference has already been made.

Through the kindness of Mr. Delany, some of the sensitive paper tape used in his system of machine telegraphy was obtained for experiments with the synchronous transmitter. A simple method of obtaining records of currents with this tape, which is certain in its action and does not involve any special apparatus, is to place the tape upon a smooth metal surface, which serves as one electrode, and to draw a steel needle, serving as the other electrode, along it guided by the straight edge of a ruler. If a direct current is used, no record appears when the current is in one direction, and it does appear when the current is reversed. If a second needle is substituted for the plate electrode, the record appears on one side of the tape for a direct current and on the other side for the reversed current.

If the two needle electrodes are placed side by side upon the tape, a record will appear at one needle for a direct current, and at the other for the reversed current. Employing the alternating current with the single needle and plate as electrodes, the record shows a regular succession of distinct marks, separated from each other by equal intervals. Each mark exhibits an intensity varying approximately according to the sine curve. Since by this arrangement the current makes its record in one direction only, the result is that alternate semi-cycles of the current are suppressed, and alternate ones are recorded.

By receiving with two needles side by side, all the alternations are recorded, those that were suppressed before now appearing at the second needle. The record then appears as two parallel lines of marks having the maximum intensities in one line opposite the spaces in the other. Using the transmitter as already described with a semi-cycle as a unit in preparing the tape, and receiving in two lines, it is found that some of the marks are omitted in one line and some in the other, and to facilitate translating it is simpler to bring the two lines into coincidence to observe the dots and dashes of the message. A message was then prepared upon the transmitter wheel, using a complete cycle as a unit, instead of a semi-cycle. When received in a single line this message is complete, no matter to which terminal of the circuit the receiving needle is connected, because each unit now contains both a direct and a reversed current, one of which will record.

The same message was then received in two lines, and one line gave the complete message as before, while in the other line there appeared a record for each complete unit in which the current was made. The papers of either the first or the second half of each complete cycle composing the message upon the wheel were next removed, and the message received in two lines as before. The result showed the message complete in one line, while in the other line appeared an uninterrupted succession of marks just as given by the simple alternating current received in one line.

If then an uninterrupted line of marks can be received in one line at the same time that a message is being received in the other, this uninterrupted line can be used for a second message entirely independent of the first. The next experiment accomplished this, and it is now possible to use the same line to send two entirely independent messages in the same direction at the same time at a high rate of speed. The preparation of the transmitting tape to accomplish this, simply requires that the two messages, each prepared with a double unit, shall be displaced a semi-cycle with respect to each other as they pass through the transmitter.

The advantages of duplexing the line, that is, sending two independent messages in opposite directions over one wire at the same time seem more important than those of diplexing the line. An arrangement of circuits which accomplishes this proves to be very simple. Moreover it permits entirely different frequencies to be employed by the transmitters at the two ends of the line, and as before involves no synchronous receiver at either end. By duplexing the line the speed of transmission over a single wire is practically doubled; for example a line that carries 3000 words simplex can carry 6000 words per minute duplex.

It is desirable in many cases to manifold the original copies of the message received, and experiments were made to accomplish this. All that is necessary is to attach to one terminal, instead of a single needle, as many needles as the number of copies desired, having each make its record upon a sensitive surface. The manifolding process evidently applies to either simplex or duplex receiving. Manifold copies of messages may be received in widely different localities at the same time from one and the same transmitter, by connecting the receivers in series or in parallel.

The alternating current is adapted to use with condensers in series with the line where a direct current cannot ordinarily be employed. An experiment was carried out to send a message through a condenser having a capacity of 9.57 microfarads in series with the line, and it was found that the message was transmitted correctly. One object of this experiment was to establish the possibility of using a set of Morse instruments upon the line at the same time that the messages were being transmitted at a high rate of speed by the alternating current. By shunting condensers around the set of Morse instruments it was found that the operation of either system did not affect the working of the other, so that it becomes possible to use the same high speed line for a complete system of quadruplex telegraphy at the same time. Indeed it seems possible that the present Wheatstone system could be operated over the line in conjunction with the alternating current messages. The experiments with the chemical tape which have been outlined above, together with others not here given, demonstrate the flexibility of a system of intelligence transmission employing the alternating current.

The use of the alternating current as a means of sending intelligence in connection with the fact that a message can be sent through condensers, suggests the possibility of using the principles of electrical resonance employing circuits having natural periods of their own which will pick out and respond to currents from the line having their own frequency.

Although the above illustrations have employed for the most part the Continental code representing a dot and a dash in a particular manner by the omission of certain waves, and the spaces between letters and words by the presence of waves, yet it is evident that this is but one of many combinations which this system permits, and that mentioned above is not to be understood as representing the most desirable one.

A characteristic of the records made by electrolysis is the natural separation of the positive and negative waves of current, which is an advantage in interpretation. This separation is also accomplished in the polarizing receiver by employing two receiver tubes. Instead of setting the polarizer and analyzer for extinction they are so placed that some light is normally transmitted through each tube. The tube coils are so connected that a positive current produces approximate extinction in one tube, and a maximum transmission of light through the other. A negative current transmits a maximum of light through the first tube, and produces approximate extinction in the second. An alternating current therefore causes a record of the positive waves through one tube, and the negative waves through the other, and thus accomplishes all in this respect that the chemical receiver does.

THE LINE.

It is generally understood that the line limits the speed of telegraphy. The limit is usually reached because of the distributed electrostatic capacity of the line rather than its resistance. The influence of the distributed capacity is to change the form of the wave as well as reduce its amplitude. With a given length of line having a certain static capacity, there exist limits to the speed obtainable with any given set of instruments which would be a difficult mathematical problem to predetermine. The difficulty in making this calculation is in the influence exerted by the particular instruments used. With different instruments the upper limit of speed is very different with the same line. It therefore seems that the only way to determine this question is by submitting the system to actual trial over a long line.

In order to test this system over as long a line as was available, the land telegraph and telephone lines upon the military reservation at Fort Monroe were joined in series, making about thirteen miles of iron wire having a resistance of 320 ohms. Not only was no difficulty experienced in transmitting and receiving messages over this line, but resistance was introduced making about 1,500 ohms total including the polarizing receiver coil of 390 ohms. This trial was at a frequency of about 200 complete periods per second. With the chemical receiver a coil of 10,900 ohms was used in the laboratory and the record was plainly received at a frequency of about 545 complete periods per second.

Since the polarizing receiver gave indications showing the approximate strength of the varying currents by the intensity of the light upon the plate, it was used to study the effects upon the currents of arbitrarily introducing capacity and inductance in series into the line, especially the effect upon the make of an alternating current at different points of phase. Fig. 15 shows the general appearance of the simple alternating current with different exposures, at different speeds of the plate and the same frequency of alternation. In Fig. 10 the inner record C is that of a circuit having 390 ohms resistance, 1.03 henrys inductance, and 4.78 microfarads capacity at a frequency of 137. At each make it is observed that the first wave is small, followed by a large one. The record at D is for a similar circuit in all respects except that the capacity is doubled, being 9.57 microfarads. Theoretical curves[1] have been computed for these cases and they are in agreement with the records shown.

The method of neutralizing the effects of the distributed

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[1] "The New Polarizing Photo-Chronograph"—*Journal of the U. S. Artillery*, Fort Monroe, Va., Nov.-Dec., 1896.

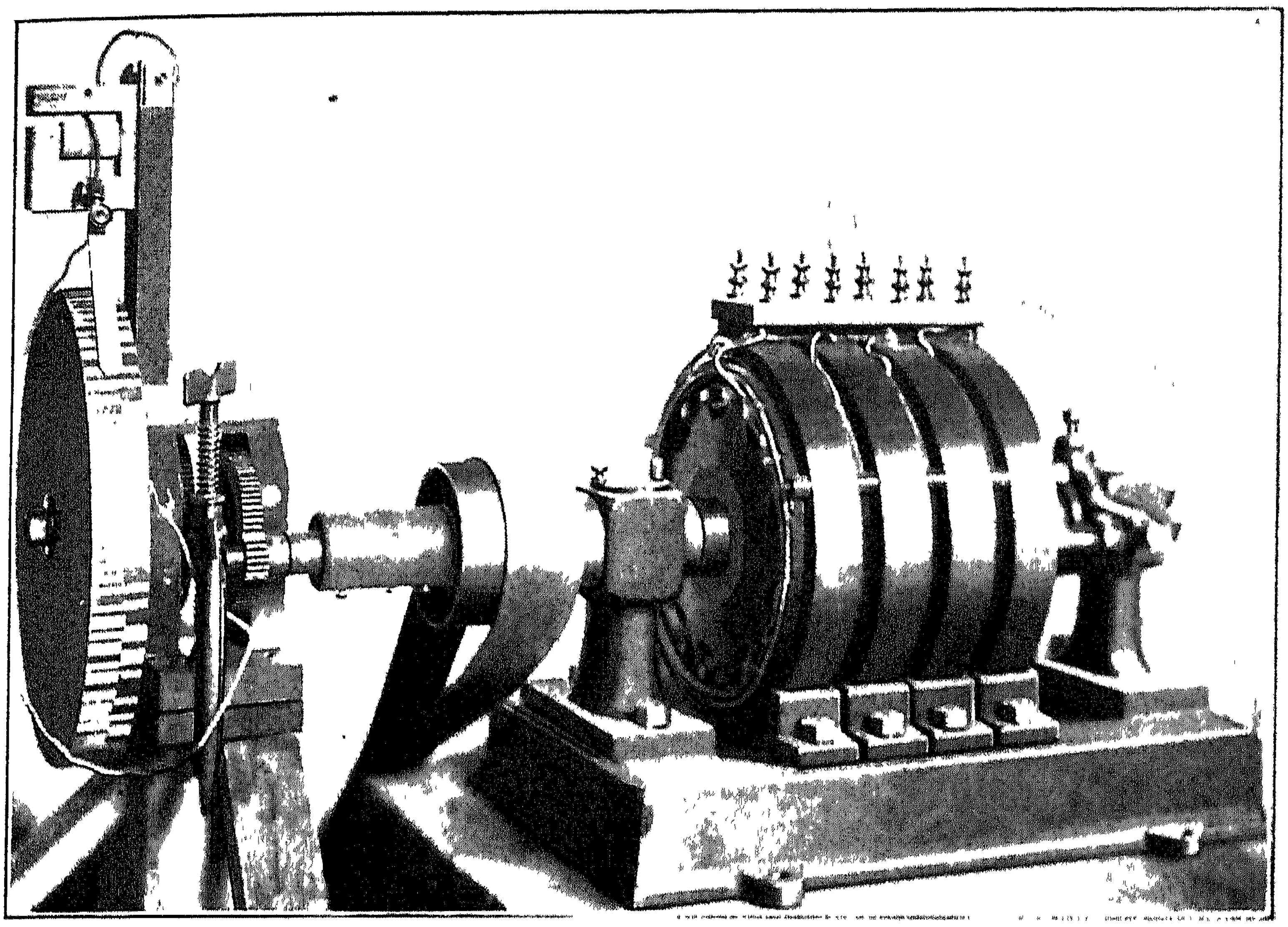

Fig. 13. The Pupin High-Frequency Alternator, attached to Synchronous Transmitter.

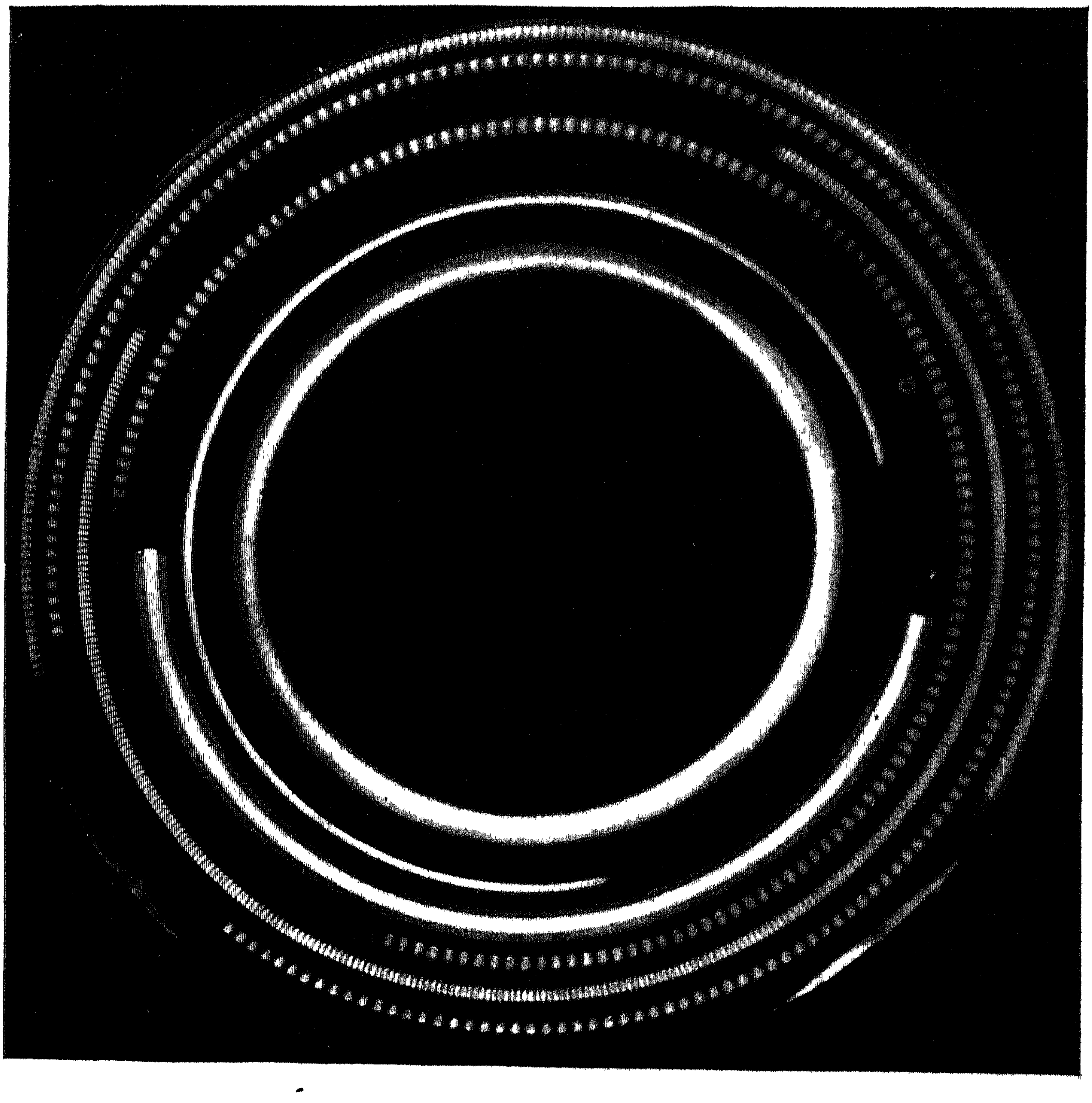

Fig. 15. Chronograph Records of the Alternating Current, under varying conditions of circuit and speed of plate.

capacity of lines by introducing distributed inductance as is now done in some telephone lines, would have an especially useful application in a line employing the alternating current for telegraphy.

CONCLUSION.

When the extent of the transmission of intelligence at the present time is considered, and the direct influence which this service has upon the development of the world's progress, any proposition which promises to increase its efficiency should be received with consideration.

To better comprehend the volume of this service it is of interest to observe the statistics on the subject. These have been prepared for the United States mail service, the Western Union Telegraph Company, and the American Bell Telephone Company of the United States, and are exhibited in graphical form in Fig. 16. The statistics for the United States Mail service for the last few years were furnished through the courtesy of the Postmaster-General.

It is noticed in general, that there is an increase in all departments of the intelligence transmission service from the earliest dates. The number of pieces of mail sent during 1896 was 5,693,000,000 which is the greatest amount ever sent in a single year. The greatest number of telephone messages on record for a single year is 757,000,000 in 1895. The largest number of telegraph messages was sent in 1893 and amounted to 66,000,000. Thus the greatest number of telegraph messages as compared with telephone messages is in the ratio of 1 to 11½. The greatest number of pieces of mail is in the ratio of 86 to 1 as compared with telegraph messages, or in the ratio of 7½ to 1 as compared with telephone messages. It is also seen that the cost of the mail service of the United States in 1896 was $90,626,000, or about $1.25 per capita. The greatest receipts for any year of the American Bell Telephone Company were in 1895 $16,400,000, about 25 cents per capita, while the greatest receipts of the Western Union Telegraph Company were in 1893 $24,978,000, about 35 cents per capita.

It appears therefore that the people of the United States pay for a telegraph service of about one-eighty-sixth the amount, about one-fourth of that paid for the entire mail service of the United States. It also costs one-and-a-half times as much for telegraph service as for the telephone service, although the number of telephone messages is about eleven-and-a-half times as great.

A conclusion to be drawn from the above general data seems to be that the people are willing to pay more in proportion for a kind of service like that of the telegraph than any other. From the point of serving the people, as well as from a business standpoint, it appears that improvement in this class of intelligence transmission is at present much to be desired. The present state of the art of telegraphy points to improvements along the line of automatic machine transmission.

It is of interest to inquire what effects a system of telegraphy capable of sending continuously 3,000 words a minute would have on the existing methods. To take a single example of the business between New York and Chicago, where about 40,000 letters are carried daily, it would require but two lines in continuous operation to handle the entire business. At present it takes three days to receive by mail a business reply between New York and Chicago. This transmission by machine telegraphy could be accomplished easily the same day. It is thought that an effect of this would be to increase business transactions to such an extent that the total volume of intelligence transmitted would be augmented, rather than to diminish the business now done by existing methods.

The class of business which such a system would probably at first obtain would be the less urgent telegraph business of greater volume, such as the Associated Press dispatches and newspaper press reports. Among the possibilities is the simultaneous publication of the same newspaper in different parts of the country. For example, in an edition of a daily paper having twelve pages and eight columns per page, making ninety-six columns in all, there are less than 185,000 words. At the rate of 3,000 words per minute it would only require about an hour to transmit the entire contents of the paper. This calculation furthermore assumes that the whole paper is uniformly printed in fine type. It would require a single operator, working by hand and averaging twenty words per minute, over six days of twenty-four hours each to send this amount.

The system proposed is especially adapted to meet the demands of this class of business; for the great flexibility of the alternating current as employed, permits if necessary considerable amounts of power to be transmitted over the line which may be used for making simultaneous manifold copies of the same dispatches in each of widely separated cities. In this manner each of the several newspaper company subscribers in each city receives the identical service with the minimum delay, since each copy received is an original. Each additional subscriber to this service represents no appreciable expense to the company, since it requires but another receiving needle. Furthermore, the use of the alternating current permits the line to be used quadruplex at very rapid speeds, that is, four entirely different dispatches may be sent over one wire at the same time, two in each direction, and any number of copies of one or all the dispatches may be received independently at the same time.

In addition to the above it is practicable to employ the line for a system of the ordinary quadruplex telegraphy at the same time. In trial experiments in the laboratory, particular instructions were given to the operator of the Morse instrument to observe if possible when messages were being sent by the alternating current, and absolutely no effect was detected.

The objection may be urged, that it is already difficult to handle the business at the present rate of operation of the Wheatstone system, and if the instruments worked faster it could not be handled. This objection is undoubtedly a real one in some cases, and it is partly this fact which indicates that it may be easier to inaugurate new methods than to attempt to adapt the new rapid transmitters to the present methods.

A telegraph office of the future will probably present a different appearance from that which may now be seen in any of the large cities. At present in operating the Wheatstone system in this country, sending to long distances at the rate of 150 to 200 words per minute, both those who prepare the sending tape and those who translate the receiving tape are employés of the telegraph company and are near the sending and receiving instruments. If it requires about ten men to prepare tape, and as many more to translate it for a single instrument operating at 150 words per minute, it will require twenty times this working force for one of the rapid machine transmitters. Evidently changes would be required in the present methods to handle this business.

It is thought that a telegraph company of the future will fulfil a somewhat different function from the present ones. The company will own its wires and rights of way as now, but the tendency of the offices proper will be to transmit and receive letters already prepared rather than to undertake the preparation of the letters as well. The income of the company will be derived from the rent of its lines at a fixed price per minute, or a fixed price per hundred words. The service of the telegraph office then becomes like that of the post office, its duty being to receive and deliver letters already prepared, as the post office does. The difference between the two offices is in the manner in which this is accomplished. The telegraph office becomes a post office which employs an electric current in a copper wire to carry its letters instead of a railroad train. The advantages in point of speed of delivering letters by the former method are apparent. Instead of requiring twenty-four hours to deliver letters between New York and Chicago, it will require but a few hours at most, and make it possible to receive a reply the same day. It is probable that such a system would take more business from the present postal system than any other; for when telegraph letters can be sent at reasonable rates comparable with postage, in a few hours instead of many days, a certain amount of present post office business will be diverted. More than this, when business can be done with greater facility than at present, the total volume of business will undoubtedly be increased, because transactions may take place in a day which formerly required a week.

It would be to the interest of such a company to seek that class of less urgent business now done by correspondence, rather than the class handled by the present telegraph companies, where the highest speed of delivery is expected. If one trunk line becomes established between large business centers, it will draw business from a surrounding area. For instance, if a line were established between New York and Chicago, and a person in Albany desired to communicate with Chicago or points beyond, it would be quicker to send the letter to New York for transmission over the trunk line to Chicago, and then by rail to its destination, than to send directly by rail from Albany. With a few trunk lines in successful operation it would not be long before they would be multiplied.

It is understood that these telegraph letters are sent by mail in envelopes in the usual manner, except that the envelope contains the prepared message ready to be sent through the transmitter, and thus the telegraph office becomes relieved of the preparation of the letters which is not strictly a part of its business. When the system comes into general use, business offices will have their own perforators, and it will become necessary for the operator to learn the telegraph alphabet as a part of his preparation as a stenographer and typewriter. The three-key perforating machine is comparatively inexpensive, but undoubtedly a machine could be devised at an early date, as an attachment to the present typewriter, for the purpose of perforating letters at the same time that they are being written by the typewriter in the usual way. This could be constructed to operate by the use of electromagnets, and can be attached to a typewriter without interfering in any way with its operation. No extra power would be required, for this can be derived from an electric current which operates the attachment. The writing may be perforated at the present rate of speed of typewriting without the operator having any knowledge of the telegraph alphabet as far as perforating is concerned. This machine will cost more than the three-key perforator, but it would in a short time more than pay for the difference in cost on account of the great gain in speed, and also because it prints a copy of the letter which may be kept on file. Before these perforators are introduced into common use it will be necessary to establish offices in the immediate vicinity of the terminals of the trunk lines, to prepare letters for persons furnishing printed or written copy, as well as to furnish a printed translation when desired of letters received from the central office. The opportunity to obtain a cheaper rate for prepared letters will act as an inducement to those employing a stenographer to add a perforator to their offices.

Concerning the daily correspondence of the large business houses between cities which are the terminals of the trunk lines, it might be an advantage for them to have exclusive use of the line for a certain number of minutes daily at a certain fixed time of day, by subscribing and paying an annual rental to the company. Knowing definitely at what hour the mail would be dispatched daily, it would then be possible for each house to send by messenger its daily mail already prepared for transmission to the general transmission office, where it could be placed in boxes prepared for the subscribers, to be taken out and transmitted when its time arrives. The distribution at the receiving end of the line could be accomplished as now by the regular mail service.

In the limited use of rapid automatic intelligence transmission at present, the sending and receiving records are made upon prepared paper in the form of tape. In the larger volume of business which is being considered here, it does not seem certain that tape would be the best form for the sending and receiving paper. It would be an advantage to have the letters received upon sheets of paper with the dots and dashes arranged in parallel lines. Besides facilitating the reading, this form would be more convenient for mailing. It would also easily permit reference to any part of the letter at a glance. The amount of paper required by the use of sheet form instead of tape would be reduced, which is an item of importance where such a volume of business is being handled. Sending and receiving from the surface of a cylinder seems entirely practicable.

Another point which must be considered is whether with these systems, the induced currents from neighboring wires along the line or from any other cause will affect the legitimate signals materially, as has been at times the case with the Wheatstone system. In reply to this it can be said that these receivers for telegraphy are not necessarily more sensitive to small currents because they are rapid. On the contrary, they may be made to require as much current as is found desirable to rid them of the effects of outside influences, and at the same time retain the property of quick action in response to currents of the proper magnitude. In this connection it may be said that the utility of a single line wire becomes so great that more attention will be given in the future to the line construction and maintenance. If millions of dollars are invested in the construction of a single railroad, is it not as necessary to make the telegraph lines which carry important and profitable business as perfect in their construction?

The telegraph line of the future will comprise substantial poles carrying a few copper wires worked to their full capacity for transmitting electric signals. The cost of maintenance of such a line when once constructed will be little more than for an ordinary iron wire now used, while its carrying capacity for intelligence at 3,000 words per minute simplex will be about equal to 160 wires used for hand transmission simplex. By duplexing the line, the carrying capacity is doubled and becomes 6,000 words per minute, which is about equal to 160 wires worked duplex, or to 80 wires worked by hand quadruplex.

It is thought that the influence which the inauguration of a telegraph letter system would have upon the existing telegraph and telephone business would be to increase rather than diminish it. Each of these services has its own special field of usefulness but little affected by the others. A new field would be occupied rather than an old field supplanted. The present telegraph and telephone would still have their natural field of operation. even though the best hopes for a telegraph letter service are realized.

A single line capable of sending 6,000 words per minute between New York and Chicago, becomes a different kind of investment from a long distance telephone line where the number of words per minute with the fastest rate a speaker can talk is very slow in comparison, and the charge is $9 for five minutes' use of this line.

The application under government control of a rapid system of correspondence transmission such as has been outlined, operating in conjunction with the present postal system, by supplementing and relieving their service could hardly fail to prove of benefit to the people of the United States. This comes within the proper duty of the Post Office Department, and would be under the direct control of the Postmaster-General. The simplification in operation and expense which would result from uniting directly with the general post offices of large cities the telegraph letter service would soon be realized by the people and a better service insured.

As a practical means toward ultimately assuming the direct responsibility of this new service, it would probably be easy to secure private companies which would be willing to contract with the Post Office Department to transmit telegraph letters at a fixed rate for a term of years. In this manner the Department could gradually absorb this branch of its business and be relieved of any sudden new responsibility and radical reorganization.

It is not thought that the development of a rapid intelligence transmission service to the extent suggested could be accomplished before many years, nor indeed that the manner or means of this development should closely follow the lines indicated, but that something analogous to this development seems among the possibilities if not the probabilities of the near future.

The persistent efforts of Mr. Delany and the great system which he has developed are well known, and the ideas which he has advanced in regard to the applications of rapid systems are in the main in accordance with those stated herein.

DISCUSSION IN CHICAGO APRIL 21ST 1897.

(Mr. A. V. Abbott, in the Chair.)

DR. FREDERICK BEDELL:—It gives me great pleasure this evening to read a paper prepared by Dr. Crehore, with whom I have been so closely associated in scientific work, and Lieut. Squier. The paper deals with a system of high-speed telegraphy, the speed attained being far beyond the speed reached by the methods now in vogue. The paper is a long one, and as each of you have a copy of it in hand, I will pass rapidly over the minor details, and devote more time to the salient points of the paper.

[Dr. Bedell then read the paper.]

PROF. W. M. STINE:—I would like to have you explain how the plate is held, and the mechanism of the revolving disk, also how the exposure of the plate is effected. Is the apparatus used in the light?

DR. BEDELL:—The plate is held in a light-proof plate holder. The whole apparatus is used in the light. When used as a chronograph for determining the velocity of projectiles, the operator presses a key, and a circuit is closed which starts the projectile; the shutter is opened automatically by means of an electro-magnetic device, so that the shutter is only open during the time of one revolution of the plate. This instrument (the Polarizing Photo-Chronograph measuring instrument) can be read to one one-thousandth of a degree, and estimated to one ten-thousandth of a degree.

MR. A. V. ABBOTT (the Chairman):—Gentlemen, I for one feel we have listened this evening to a paper which will take us some time to digest, and assimilate, for the bearing of the subject upon that portion of electrical science with which it deals is of great importance. The only criticism which I could make upon the paper is, that the authors have failed to show a plan for doing away with the telegraphic system entirely, and do not indicate to us how to transmit intelligence by intuition from person to person, in all parts of the world at the same time. The salient point which has occurred to me this evening is the simplicity and at the same time the ingenuity, which the authors have displayed in their apparatus. The idea of transmitting signals by suppressing half of each wave at precisely the right time, so that the inductance of the line would have but little effect, seems such a simple and yet effective thing that we all wonder why we had not thought of it ourselves. But how to get an inertialess receiver, which was the question that occurred to me, to get something that would record those signals and place them on record, and in such shape that they could be translated and read,—it is a wonderful thing. To institute a set of signals is one thing; to receive and place them on record is a very different problem, and I think even Faraday would have been greatly surprised if anyone had predicted to him that the discovery of the effect of a magnet on a ray of polarized light could be made the basis of such an invention.

Mr. W. W. Ryder:—In railroad work there would hardly be a possibility, or I should say a probability, of an extended use of this system, as there is never a large accumulation of messages between any two points that would require such speed of transmission.

I realize, however, that it would mean a great deal to the commercial telegraph companies if this scheme could be put into practical operation upon the present telegraph circuits. There is always a great amount of business constantly passing between the larger cities, and such a system would be of great benefit in quickly handling it. This would be especially true when the wires are prostrated by storms. The messages could be prepared for transmission and as soon as the first wire was repaired, the business could be started at a rate that would quickly relieve the congestion.

Mr. Abbott:—Humanity is never satisfied and always wants something a little better, or a little quicker; though I have heard it said that when railway postal facilities were first talked of, they were objected to by the more conservative as being entirely unnecessary, for had they not had a postman on horseback, who could travel five miles an hour, almost as fast as the railroad train of those days, and what did they want better than this? Besides, if there were better facilities, too much time might be spent in writing letters. When the telegraph came fifty years ago, the same objection was made; there were good postal facilities, and when the telephone came, there was the telegraph and the district messenger service. Individually I should feel that no invention could be too quick for us in this country. The faster we can work telegraph lines, the more economically the messages can be sent, and the more people will use the telegraph, if transmission can be cheapened.

Prof. C. V. Kerr:—The idea that is embodied in this system is certainly a very beautiful one, and seems extremely simple. Now, looking at it from a commercial standpoint, it seems to me that at the first stage this apparatus must be limited in its use to lines where there is a great congestion of telegraphic matter. The apparatus is necessarily expensive. There must be, in the first place, the apparatus for light, and then the polarizing apparatus, and then the apparatus for getting the record after the message is prepared on the strip of paper. If the apparatus for quickening the recording of the message itself can be made as beautiful and quick and simple as are the main ideas of the apparatus, it certainly will be a wonderful system. But we have first to prepare the message itself, then develop the photographic plate. Now, that will take time, and it will be expensive, so that, looking at the system from this point of view, my first impression would be that it is going to be limited in its applications unless these points can be cheapened in some way. But it is not safe ever to say too much as to what can be done with a new invention, for again and again our ideas have been set aside by later developments.

Mr. Abbott:—The complexity of the apparatus is certainly at present formidable, but, as Prof. Kerr has pertinently added, a new invention is always more complicated than it is in its succeeding steps. It is not impossible that simplification may occur in a very marked degree. Furthermore, even with its present complexity, it is not impossible that the cheapness of wholesale business might render it an eminently successful system. I think if photographers ten years ago had been presented with the kinetoscope and its companions of a similar nature, and had been asked to take twenty or thirty pictures per second, as is now successfully done, they would have said it was impossible, or if possible, would have been too expensive, while it is an actual fact that the cost is entirely within commercial bounds.

Mr. F. E. Drake:—I confess to some considerable degree of interest in this very charming paper, having had several years experience in the telegraph. I realize the step that is here expressed, in passing from perhaps forty to fifty words a minute to three thousand words a minute, and believe there are a great many points of possible development in this system. With my limited experience in the old style telegraph, I can predict that under the careful scrutiny and painstaking zeal and ingenuity of these gentlemen, they will be able to accomplish a result which will be of great benefit to the entire world. We are so accustomed now to receiving intelligence with marvelous speed from all points of the globe, that this method is only in touch with what we most desire. From a technical standpoint, I do not feel in any way competent to express an opinion. The question of photographic plates seems to me the most serious which rises in connection with this device. Another thing which occurs to me is the fact that you have to go through almost all of the old methods in order to get your message readable, although the speed attained in transmitting is marvelous. Then again, the receiving of the messages and getting them into condition for the understanding of the press and the public at large, adds to some pressing commercial features of the present code. I believe that one of the most important advances which will be made in this direction will be the simplification of the codes to be used, and the introduction of a new scheme of phonographic telegraph, expressing synchronously words, phrases and sentences. That one point strikes me as being the greatest possibility of this new invention, and I predict we will hear from it with a great amount of interest.

Dr. Bedell:—Some of the speakers have expressed their opinion that this system is exceedingly promising, but that it possesses obstacles, which, although of minor importance, may be serious in practical ways. They have also suggested the overcoming of these obstacles as a matter of future development. Such is the case. The first endeavor is to establish the feasibility of the system, and to develop some plan which will be operative. After going thus far, and demonstrating by a series of experiments that the system is a practical one, it is proper time to determine the exact form of apparatus which will be simplest and best. For instance, the instrument shown on the screen, used as the polarizing receiver, was one constructed for chronographic purposes, with no definite consideration so far as telegraphy is concerned. However, the authors of the paper have developed two forms of receiver, one of which has been partially neglected in the discussion this evening,—the chemical receiver. The chemical receiver may be used, and it was dwelt upon at less length because it needs less explanation. The polarizing receiver was discussed more at length because more of the early experimental work was done on that receiver, and it has many features which are worthy of consideration. The chemical receiver, however, in the minds of the inventors, possesses many points of superiority over the polarizing receiver. They thus secure a receiver which possesses a degree of simplicity comparable with that of the transmitter. In regard to the polarizing receiver, it may be said that a simplification has already been made. The authors of the paper suggest the use of a continuous tape instead of a disk, this tape passing through a developer, and coming out already fixed. It seems that this apparatus could be arranged so as to be, in a way, comparable with the chemical receiver. There is no doubt that if the system receives careful attention, as it is sure to do, sundry details will be perfected, and simple instruments devised. This development, however, would simply be in the way of modification of the general idea, that is, of transmitting signals by suppressing distinct predetermined half-waves of an alternating current, and to receive them by some kind of massless receiver.

MR. ABBOTT:—I think that Prof. Stine has voiced the thoughts of most of us, particularly, if we take into consideration the capacity of the apparatus proposed. This device, undoubtedly, would be very expensive if it were to be applied only to the transmission of a few words a day, or messages of a few words each. But even a fraction of its capacity would indicate that it undoubtedly would be very much cheaper than any system we now have. It is, undoubtedly, somewhat complex, and may require considerable apparatus and skill for its installation and operation, but it will enable communications to be sent with marked economy over anything now in sight. I think we should have but little doubt but that the volume of business would come just as soon as a commercial showing indicates the possibility of cheaper transmission than we now have.

MR. W. D. BALL:—First of all, I want to add my little mite to the words of praise which have been given to the paper read to-night. I am like a good many others who are here,—I have not been able to digest it, but I am something like the small boy who can ask questions, if he can't do anything else. There are a few points which I would like Dr. Bedell to take up more at length, if possible, with regard to the practical application of the working of the apparatus. In the first place, I might say I would not be willing to admit at present its greater economy in the matter of transmission of messages until we have some practical data regarding the amount of time taken for preparing the ribbons and photographic plates, etc., and for the expense of the force necessary to take care of the transmission, repetition and recording of messages. The figures shown on the screen have aptly illustrated the paper, but I believe nothing was said with regard to the amount of energy necessary to transmit messages. I take it, of course, that the difference of potential impressed upon the circuit would depend almost entirely upon the length of circuit, the resistance to be overcome, etc. If Dr. Bedell can, I should be very glad to hear him tell us of the voltages used, and give us what other practical data he may have regarding it. It is unfortunate that we did not get copies of this interesting paper in time to have read them over. Possibly these points are touched upon in the paper. At the same time, I should like Dr. Bedell to dwell a little more at length on the effect of induction in the lines and the possibility of long distance lines, both as affected by the inductance of the lines and by the frequency of the alternations.

DR. BEDELL:—I regret that the inventors are not here to answer some of these inquiries, for they are all questions of detail with which I am not sufficiently informed to give adequate answers. I do not know the exact electromotive force employed in their experiments; nor do I have practical data concerning the line, its length, capacity, and resistance. The line was a short, experimental line, which had its actual length increased, however, by resistances inserted in the laboratory, and the authors have made computations as to the feasibility of long-distance telegraphy, which have resulted favorably. If it does come, however, to a question of increased cost of line construction, as it undoubtedly would where there are long distances, as across the continent, we could well afford to put a good deal of money into a line where we had but one to maintain, instead of many. One point concerning the labor of preparing the perforated tape: the labor, unless some special device is introduced, would be the same, no more and no less, than there is now in the methods of machine telegraphy. It has been suggested by the authors that the work of translation, so to speak, be thrown upon the individual. That is, we dictate a letter to our stenographer, who transcribes it upon the typewriter by performing two operations at once, one, preparing a copy of the letter in readable form for preservation, and the other preparing the perforated tape. This perforated tape is then put in an envelope and dispatched to the sending station. The sending station would not then need a large force in transcribing messages, but simply enough men to operate the machine proper, the other work being transferred to the private office. However, too much cannot be done at once. The step which has been taken is to eliminate the time element in the necessary part of the transmission.

MR. LOUIS PRIVAT:—I should like to ask Prof. Bedell one question before we close our discussion. Could this system be applied to Trans-Atlantic cables? It seems to me that this is a place for great economy, if it could be used in that manner. It seems to me that an invention of this kind, which would distribute so much intelligence in such a short time, would be particularly desirable there, where, under the present method, transmission is so expensive. This system would undoubtedly be much cheaper.

DR. BEDELL:—Cable transmission by this system has not yet, I believe, been subjected to experiment. It has been contemplated by the authors, and a cable has been placed at their disposal to be used at such time as they are ready to undertake that experimental work; but the time at their disposal has not yet allowed them to avail themselves of this opportunity, for they have found so many other points of detail to occupy their attention that they have had to forego this experiment. I do not doubt, however, but that it will be taken up in the near future.

PROF. STINE:—We have all been delighted with the paper which has been presented to us this evening, and the very clear, full explanation which has accompanied its presentation. I think all present will cordially join me in a vote of thanks to Dr. Bedell for his kindness in coming to us to read the paper, and taking such an interest in explaining it.

(The vote of thanks was unanimously carried.)

Discussion in New York May 18th, 1897.

(President Duncan in the Chair.)

Mr. **Francis W. Jones**:—The proposition to increase the efficiency of the electric telegraph by the employment of some automatic system that will admit of the transmission of several hundred and even thousands of words continuously per minute has been a favorite one, not only with visionary and impractical minds unfamiliar with the every day demands of the telegraphing public, but the idea has been cherished by practical telegraph engineers of the most distinguished ability ever since the conception of the electric telegraph both here and in England, the two countries that have led all others in bringing to their present state of perfection the wonderful systems that are being employed upon the land and submarine wires of the world.

It is not complimentary to the managers of the great telegraph systems of the world, particularly those of Great Britain and America, to suppose that they would go on year after year putting up hundreds of thousands of miles of new wires, the majority of which are pure copper, to meet the increasing demands of the public, or to allow the post office to carry an enormous volume of mail matter by railroad, when by the employment of a system similar to the one proposed, as much business could be transmitted from New York to Chicago in 10 hours by one wire, as is now done by 100 wires worked quadruplex.

That there have been very high speed automatic systems put in operation at a great expense is a matter of record, and I believe that the failure of such systems to bring about a cheaper and more rapid handling of telegrams was in no way due to inability to transmit and record the signals fast enough over the wire, but was due to other and very different things, so I do not deem it necessary at this time to enter into any discussion of the particular method of transmission proposed under the name of the "Synchronograph," but will endeavor to present a few stubborn facts which so far have stood in the way of the realization of the joint inventors' vision of the practical application of sending 3,000 words per minute between New York and Chicago, and performing the entire postal service represented by 40,000 letters daily upon two telegraph wires.

Latimer Clark, President of the Society of Telegraph Engineers (now the Institution of Electrical Engineers) in his inaugural address in January, 1875 in giving a history of the development of the British telegraph system under the various companies prior to its consolidation with the post office by the British Government, said:

"The chemical printing telegraph of Mr. Alexander Bain deserves a special notice. Chemical telegraphs were suggested at an early date, and in 1838 Mr. Edward Davy patented a chemical marking telegraph of considerable merit employing calico tapes moistened with iodide of potassium. In 1846 Mr.

Bain patented his system, and in addition to the use of an iron style resting on paper moistened with a solution of ferro cyanide of potassium described the important principle of setting up the messages on perforated paper, a system which has done more to increase the capabilities of the telegraph than any other invention.

"That invention was exhibited to the Electric Telegraph Company, and while being examined, one of the regulating springs broke and allowed the instrument to travel around with uncontrolled speed. To their surprise they found that the whole message was visible and had been transmitted correctly at the rate of several hundred words per minute upon which they resolved to purchase the invention without delay. I believe Mr. Bain received £7,000 for his patent."

"They employed the system of printing on chemical paper for some years until it was eventually supplanted by the Morse inking system. Nothing however was done with the punched paper until Sir Charles Wheatstone introduced his very beautiful automatic printing telegraph which is the most rapid system of telegraphing at present in ordinary use.

" Real capabilities of the Bain system remain however to be yet developed. The Americans have recently reintroduced it with startling results, and have shown that on ordinary circuits 400 or 500 words per minute may be readily transmitted by its means. When the capabilities of this system become generally known to the public, it will doubtless insist on enjoying the advantages to be derived from it, either in the form of lengthened messages or a lowered tariff.

"Without some such system much of the celerity to which we are now accustomed will be lost amidst the enormous accumulation of work which must sooner or later fall upon the telegraphic system of this country. The electric telegraph is quite capable of transmitting a large portion of the business of the country which is now transacted by letter, and is being so enployed more and more every day. If this expansion of traffic be accompanied by facilities for securing rapid transmission for important messages the pecuniary gain to the post office will be very great, while the benefits afforded to the commerce of the country will be enormous."

Mr. Clark was engineer for the principal English telegraph company prior to its being absorbed in the government system in 1870, at which time a uniform rate of one shilling for twenty words with addresses had been adopted, and the public led to believe that by bringing the lines of five or six different companies under the management of the post office, and by the use of the Wheatstone automatic system, that an enormous volume of business could be so economically and readily handled that the tolls could be lowered almost to postage rates.

According to Mr. Preece's paper read before the London

Society of Arts in May, 1887, the Wheatstone automatic syst had been constantly improved until it had a transmitting cap ity between London and Ireland through the channel cable follows:

Year.	Words per min
1870	50
1875	70
1880	150
1885	250
1887	450

The number of messages transmitted by the British syst immediately after the transfer to the government under the s ling rate, was about 12,000 messages of 30 words each per c which upon the basis of calculation that has been usually adop by the advocates of high speed telegraphy, could have all b done in eight hours upon 5 Wheatstone duplex circuits at rate of 80 words per minute each way. Notwithstanding we find that Mr. Preece in the foregoing mentioned paper st as follows:

"The rapid increase of business that resulted from the unif shilling tariff soon led to the erection of more wires, and multiplication of wires soon attracted attention to methods duplexing and quadruplexing the circuits. The duplex sys means a mode of sending two messages in opposite direction the same time. This was shown to be possible by Gintl, Vienna, in 1853, but the necessity for such a system did arrive until 1872, and as the moment a want is felt somethin sure to turn up to supply this want, so when the duplex needed, Mr. Stearns arrived from America, with a well wor out practical system that was at once adopted, improved, perfected. Still further congestion arising, quadruplex work or the art of sending four messages on one wire at the same ti became desirable, and a practical quadruplex system, due to Edison, was imported in 1877 from the same inventive and p tical, region, the United States. Later on in 1885, a still furt development was matured in America, viz., the multiplex sys of Delany, by which six messages can be simultaneously s which we have adopted, and the main features of which I show you in action. The chief reason why these systems h been matured in America is that the want has been experien there before here. Neither system was invented in Americ each was invented in Europe. There are other wants that h been experienced here before there, and those who have vis the States have found that English inventions are equally app ated and adopted there. It is in automatic telegraph that have made the greatest advances."

The editor of the London *Telegraphic Journal*, January 1875, says, "The Postal Telegraph Department has during year (1874) introduced the sounder as much as possible, an may be now definitely considered as the instrument of the fut its various advantages have at last become apparent, and in time we shall observe its use as wide and extended as may be seen in the United States."

"The duplex continues to advance, and the Stearns system is rapidly becoming extended. The advantages derived from the system of duplex working have daily become more and more apparent."

In 1885 the clamor of the press and the pressure of the various provincial Chambers of Commerce caused the British Parliament to inaugurate a telegram rate of sixpence for twelve words, counting addresses and signatures, and a press day rate of 75 words for one shilling, and between 6 P. M. and 9 A. M. a night rate of 100 words for one shilling with addresses free, and twopence for every drop copy.

To prepare for the expected increase in business $2,500,000 were expended to meet the increased traffic, of which $2,375,000 were expended for new poles, wires, and instruments. There were added to the system:

850 miles of pole line, 9,200 miles new wires thereon, 11,600 miles new wires on old poles, 40 sets Wheatstone automatic, 8 Morse quadruplex, 300 Morse duplex, 350 Morse sounder circuits, 150 needle sets.

One month prior to October 1st, 1885, when the sixpenny tariff went into effect, the London Central Station was equipped as follows:

Metropolitan Department: 50 sets duplex sounders, 75 sets relay duplex, 71 Morse single sets, 55 sounders, 133 needles, 4 dials.

In the Provincial Department: 32 Wheatstone sets duplexed, 58 Wheatstone sets single, 17 quadruplex, 18 duplexed registers, 93 duplexed sounders, 45 Morse sets, 37 sounders, 28 needles.

Making the total number of circuits 698 Morse, 161 needles, 4 dials and 122 Wheatstone.

The Wheatstone sets were located in the news division of the Provincial room, and about 70 transmitters were kept busy sending out news. The pneumatic punchers perforating three or more slips simultaneously, the same news answering the wants of newspapers in almost any part of Great Britain or Ireland, served by many diverging circuits from London, and during the year ended March 31st, 1885, 33,278,459 messages including press reckoned at the rate of 30 words per message were transmitted.

On July 25th, 1887, the Postmaster General at the English Telegraph Jubilee dinner in London after describing the development of Wheatstone's needle system said: "Then came another probably more even astounding development, the sounder instruments, by which messages are transmitted by sound without any record. I venture to believe that that achievement has outstripped the wildest dreams of imagination, and that the present pace of the electric telegraph between London and Dublin where the Wheatstone automatic is employed, amount to 462 words a minute."

The Postmaster General also gave the number of telegrams sent through the post office of the United Kingdom in 1886 as 51½ millions including about 480 million words of press for the London and provincial newspapers, at an average rate of twopence per hundred words and the Postmaster General states that the cost to the public revenue over and above the tolls received for the press service is not less per year than one million dollars, which is practically a subsidy for the diffusion of intelligence. This sixpenny tariff had reduced the receipts per telegram from 1s 1d to 8d, netting for the year ended March 31st, 1886, a loss of $1,115,000 which added to the interest due on the capital stock of purchase (viz $54,402,855) amounts to a deficit of $1,857,770 or a grand total loss of $12,765,045 since the public tried to do its own business at rates below cost.

Notwithstanding this loss we find Mr. E. Cox Walker in the *Northern Echo* of England, in 1887, agitating a threepenny rate with the same old arguments that had been used prior to 1870 and 1885, to inflame the public mind. I quote as follows, "There cannot be any doubt in any one's mind as to the enormous increase that would take place and the benefits that would arise therefrom to the commercial world, which is really the great user of this mode of communication. The cost of transmitting messages will of course be greatly reduced, as regards each message, by the full use made of all the instruments and wires. Then the carrying capacity of the wires is being greatly increased by the substitution of copper for iron wires, and the speed of signals has been wonderfully increased during the last year or two; news being now sent at the rate of 450 words per minute between London and Ireland and elsewhere."

On May 13th, 1892, a large deputation from the associated Chambers of Commerce waited on the Postmaster General urging the reduction of rates by allowing addresses to go free, notwithstanding the deficit for the last year was nearly two million dollars, with probably the post office bearing on its own account a large share of expense for use of offices, light, fuel, and services, that should have been borne by the telegraph service, the deficit has been yearly increasing up to the present time. The traffic in 1885 was about 100,000 telegrams of 16 words, a day.

To transmit these messages there were in the London central station 130 single sets of Wheatstone, each set of which was, or could have been, duplexed, and capable of transmitting on the longest circuits out of London 462 words each way or a total of 831,600 sixteen word messages to and from London during eight hours every day, or a grand total of nearly 2½ million messages per day operated continuously for the 24 hours.

Besides the Wheatstone automatic there were quadruplex, duplex, and single circuits, aggregating 1100 circuits, capable of actual not theoretical, Morse transmission each one at the rate of over 70 sixteen word messages per hour, or a total of 528,000 messages in 8 hours.

Thirty English newspapers have special Morse wires and operators from 6 P. M. to 6 A. M. and the *Scotsman*, *Newcastle Chronicle*, *Manchester Guardian*, and some others had two wires each for news from London. It is highly absurd to suppose that because the Wheatstone system did not transmit at the rate of 1000 or more words per minute that 130 sets in London in 1887 were employed to transmit only about 1,000,000 words of press per day, when those sets had the capacity to transmit in eight hours 16,348,800 words "single" or 32,697,600 words "duplex" at the rate of 262 words per minute per set in either direction.

It is also equally as absurd to suppose that the purchase and use by the British government of the Stearns duplex, the Edison quadruplex and the Delany synchronous multiplex—all Morse systems—was due to the fact that the Wheatstone was not in itself fast enough. That the latter system would work at the speed hereinbefore stated we have unimpeachable evidence, and that its failure was not due to imperfect work is also well authenticated.

In Preece & Sivewright's work on the telegraph (1891) page 163 is as follows:

"Automatic instruments are employed on nearly all long circuits in England, not only because they increase the capacity of wires for the conveyance of messages, but because they are so specially adapted for the conveyance of news, which is such a distinctive feature of the English system of telegraphy. One batch of news is often sent to a great many different places, and as many as four or even eight slips can be prepared at one operation, and one slip can be used several times, the labor of preparing for transmission is very much reduced. It is of course evident that apart from its *extreme accuracy* the chief value of the automatic system is its increased speed of working."

In the United States the subject of fast speed telegraphy very early attracted attention, and here, as in England, it was then concluded that once a system was devised to carry several hundreds of words per minute over a wire, that a great revolution in telegraphy would follow, as will be seen by the following editorial in the *Telegrapher* of June 26th, 1869.

"We have heretofore stated repeatedly that we could see no way in which the popular demand for a material reduction of tolls could be met except by greatly increasing the transmitting capacity of the wires by automatic telegraphing, by which the practically instantaneous transmission of the electrical impulse may be made available."

Another editorial in the same journal, January 1st, 1870, says, "In connection with the question of a material and permanent reduction of the charges for telegraphic service we have consistently argued that such reduction was only possible through a very great increase in the capacity of the instruments used for transmitting communications. Further observation and reflection has confirmed this opinion, any attempt otherwise to establish cheap rates notwithstanding the one-sided argument of Washburn, Gratz Brown, Gardiner Hubbard, and other advocates of low charges, and postal telegraphs, must result in loss to whoever undertakes the work whether it be a corporation or the government."

"To successfully accomplish such an increase of capacity as is essential to a material and permanent reduction of charges for telegraphic service, the invention of a reliable automatic system is indispensable."

In 1870 a line with one wire was put up between Washington and New York by D. H. Craig and others, for the purpose of developing the automatic system of Mr. George Little, and experiments were made at great expense until 1872 when offices were opened in December of that year in New York, Philadelphia and Washington for public business.

The subject about this time appeared in a new and more practical light to the editor of the *Telegrapher*, as evidenced by an editorial inspired by our late Past President F. L. Pope on June 15th, 1872, referring to the Craig-Little system as follows:

"While the columns of the *Telegrapher* have at all times been open to the fullest and freest discussion of automatic telegraphy, we have abstained from engaging in such discussion editorially because we did not care to prejudge an experiment which was being conducted energetically and with great liberality of expenditure by the parties in charge."

"We have been aware that in experimental trials very wonderful results have been obtained. We have never doubted the practicability of transmitting signals over the wires within certain limits of distance, at any desired rate of speed. The principal difficulties and obstacles encountered in automatic telegraphy *are not* in the *transmission* of the signals; they are in the *preparation* of the slips and in the *translation* and *preparation* of the dispatch for *delivery* when they have reached their destination, the practical limit of speed must always be, not what can be *transmitted* over the wires in an hour, but what *can be prepared* for *transmission* and *delivery*.

To show to what perfection the Craig-Little system had arrived, I will quote from a letter of Craig to the editor of the *Telegrapher* dated Washington, September 10th, 1870.

"A year ago, I bespoke your favorable consideration of a new telegraph enterprise which I had then fully entered upon, and which it gives me great pleasure to inform you has now been consummated in the completion of a very *superior* line of telegraph of compound wire, steel and copper, and the perfecting of our new system of automatic telegraphy by means of which we are now transmitting from this city to New York and vice versa, 500 words per minute over one wire, a rate of speed equal to the average speed of more than 50 wires by the Morse system. The perfect simplicity, accuracy and reliability of the new system is not less remarkable than the wonderful speed above stated."

"We can by our new system transmit intelligence direct and with one writing from this city to every other city and directly into the editorial rooms of every journal in the country at the rate of 500 words per minute recording the same in clear, distinct, and perfectly accurate characters."

In September, 1870, the President of the Western Union Telegraph Company challenged Craig for $1,000 to transmit a message of 2,000 words from Washington to New York under the following conditions.

"The Western Union will use but one wire and employ but two operators—one at each end—who will not be changed or relieved during the trial. Mr. Craig shall be allowed six operators—three at Washington to prepare and transmit, and three at New York to receive translate and copy the dispatch; and whichever party transmits, makes three legible copies and first delivers them at the offices of the *Herald*, *World* and *Tribune* respectively, shall receive the $2,000. The Western Union will place at Craig's disposal two extra wires so arranged that one of them may be substituted for his own in a few seconds."

This challenge was never accepted. Craig, however, made an evasive one on September 3, 1870, that the President of the Western Union Telegraph Company should join him in depositing $10,000 with some acceptable party and if after twelve months and for five years thereafter Craig did not earn and pay to his stockholders 10 per cent. of the dividends, for every one per cent. that may be earned and paid by the Western Union, it could claim Craig's deposit."

On January 7th, 1871, George Little, the inventor, published in the *Telegrapher* a statement that it was a fact that 2,000 or more words per minute could be transmitted over a No. 8 iron wire 250 miles long.

On February 3, 1872, an adverse critic in the *Telegrapher* states:

"On the 27th of September, 1870, a dispatch of 566 words was sent from Washington to Buffalo, dropping copies at New York and Albany in one minute and twenty-eight seconds being at the rate of 386 words per minute in a circuit of about 750 miles."

On June 5th, 1872, Craig states in a letter to the *Telegrapher* "between August and November, 1870, we telegraphed by our automatic system over our single wire between Washington and New York more than 60,000 words per hour, and recorded the same accurately in clear black telegraph characters," also that he had perfected perforating machines and typewriters, also a less rapid perforator which can be worked at sight by a child and is capable of perforating 30 words a minute, to be used by business men in way offices on side lines, and under date December 23d, 1872, he wrote to the editor of the *Telegrapher* claiming that all Craig's prophesies were met, and that he had a perforator by which one operator could do over 100 words per minute, also that he could transmit and record over one wire over 300 miles long and by the aid of two girls 1,500 words per minute in good or bad weather and could transmit more matter over a single wire and by the aid of two girls than the Western Union Telegraph Company could transmit over 60 of its Morse wires with the aid of 120 high salaried operators.

This was asserted over 18 years ago, and yet the Morse operators flourish, and are to-day working by Morse system the very wires that figured so seriously from that time to the present in quixotic automatics.

In December, 1873, it was stated that the President's message of about 12,000 words had been punched and was transmitted from Washington to New York in about 20 minutes in the presence of notable government officials.

Taking Craig's lowest speed of 500 words per minute, between Washington and New York, it is easily figured that his system could transmit 8,000 messages of 30 words each in 8 hours, while the best the Western Union Telegraph Company was doing upon its entire system, embracing 137,199 miles of wire was 40,000 30-word messages per day of 24 hours.

This Craig and Little system expired from natural causes in the arms of the Atlantic and Pacific Telegraph Company in 1875. Craig in 1879 organized another machine telegraph system and started the American Rapid Telegraph Company which put about two million dollars cash in a very extensive plant with compound copper coated wires between New York, and Boston, Philadelphia, Baltimore, Washington, Pittsburg, Albany, Buffalo, Cleveland and intermediate places. The very best mechanicians and telegraph electricians were employed, and between New York and Boston 500 words per minute could be transmitted and recorded with perfect legibility. The new system was in a high state of efficiency, its operators and clerks were highly skilled. Anderson keyboard perforators were used, and all copies were made upon typewriting machines. In a test for eight days April 5th to April 15th inclusive, 1884, 3131 ordinary telegrams were transmitted between New York and Boston occupying 30 hours and 46 minutes, or at the rate of 104 30-word messages per hour or 52 words per minute.

The American Rapid Telegraph Co. was cocksure of effecting the revolution in telegraphy predicted by Craig, and with great confidence had reduced the rate to 15 cents for twenty words, addresses and signatures free, but it was soon found that the telegraphing public would not patronize the automatic system on account of its slowness in delivering messages, and Morse sounders were necessary to secure any business from a public only too anxious to favor competition. The "Rapid" system involved its promoters in financial disaster, and was entirely abandoned in July, 1884, as I know personally for the foregoing reasons, and not from its inability to record the electric signals fast enough, as it would record legibly 1,000 words per minute between New York and Boston.

The Postal Telegraph-Cable Company started the Leggo automatic system in 1881 upon two electro-copper-deposited steel wires New York to St. Louis via Chicago, two New York to Washington, two Buffalo to Pittsburg, including all the heavy commercial cities of this country. These wires had a resistance of $1\frac{7}{10}$ ohms per mile and were isolated from all other wires. These wires have never been equaled the world over. Rates were reduced, as it was a foregone conclusion with the promoters, that an automatic system that would carry over 1000 words and record them in a thoroughly reliable manner, between New York and Chicago, (which the Leggo system did) and which needed no complicated perforating machines, would not only attract all the Western Union traffic between these points but would also to a large extent empty the mail bags. After the stocks and bonds had been floated and hundreds of thousands of dollars expended for machinery, it was found that sufficient business could not be secured unless it was transmitted by the Morse system, and at the low rates established, it would be done at a great loss with such a limited number of wires, so another expensive bubble, including the company, burst.

In 1883 the Western Union Company introduced the Wheatstone system from England, although perfectly well aware of the speed of the automatic system that had been perfected in the United States. It was found that the Wheatstone system could only be employed as an adjunct to the Morse, and but eight Wheatstone circuits were put in operation and to these was assigned a class of slow freight business. In cases where it was attempted to do a general business between commercial cities the public would withdraw its business in favor of a Morse transmission. After the lapse of fifteen years, only six Wheatstone circuits are being operated by the Western Union Telegraph Company. They are all duplexed and have a total actual regular working speed both ways of 1600 words per minute. Upon the basis of computation usually resorted to by automatic advocates it is easy to see that about 70 such circuits in use only 10 hours of every week-day, will carry all the business of the Western Union Telegraph Company.

In referring to the *Telegraph Age* of December 16th, 1894, we find a record of a test made Oct. 16th, 1893, of the Wheatstone upon a Western Union wire having a carrying capacity of 400 words per minute both ways between New York and Chicago (972 miles) between 9 A. M. and 5.30 P. M. a total of 5563 regular messages were transmitted at the rate of 654½ per hour or 327 words per minute.

It required 27 punchers, 22 copyists, 4 clerks, and two electrical engineers or a total of 55 persons making 13½ messages per hour per operator.

The punchers at their best speed averaged 24 messages per hour, the copyists 30; average delay on each message in New York was 15 minutes, in Chicago 16 minutes.

This test was during the World's Fair and a highly trained corps of operators was keyed up to its highest pitch to obtain results that would astonish the foreign representatives.

On December 21st, 1896, on a postal duplex Morse circuit between New York and Pittsburg there were 341 regular messages containing 10,216 words received at New York in 5 hours or 68½ messages per operator per hour, and two hundred messages containing 5605 words received in Pittsburg in 3 hours or 66⅔ messages per operator per hour, or a total of 135 messages per hour for two sending and two receiving operators or about 34 messages per operator per hour as against 13½ by the above Wheatstone test.

Thus 19½ Morse operators could have accomplished on two quadruplexed wires, and one duplexed wire, as much as the 53 skilled persons accomplished in the before mentioned Western Union Wheatstone test.

In 1891 *La Lumiere Electrique* published a statement that in the daily operation of the French government telegraphs, the Wheatstone averaged a total of 200 messages per hour at the rate of 11 messages per operator per hour, and the Morse quadruplex 160 per hour or 20 messages per operator per hour.

The Morse sounder system is far and away the simplest and most accurate of all methods of telegraph transmission, for the reason that the sending operator need not remove his eyes from the matter that is passing out at the ends of his fingers, via the key, to the distant station, and there is not the slightest mental effort necessary to secure a ready response of the key to the necessary dots and dashes that represent the words and letters of the message; and likewise at the distant end, the eyes of the receiving operator do not move away from the keyboard of the typewriter, or the page traversed by the pen, as the hands respond without mental effort to the sounds impressed upon the ear. Not so with any automatic system (excepting perhaps the Leggo to the extent of preparing the messages) that has ever been proposed. The eyes must constantly be in rapid motion between the copy being prepared for transmission, and the machine that punches or prepares it, and in this case the eyes are very apt in returning to the matter, to fall upon the wrong letter, word, or line, or get confused and blurred from an infinite number of excursions hourly, and thus errors unconsciously creep in, besides a slowing down of the human action. The same is true in a more marked degree as to the copying from the automatic record. The eyes of the copyist have to fly back and forward between the keyboard of the typewriter and the record upon the tape and are subject to the same liability of aberration as in the preparation.

In a public address by M. J. Banneux, Chief Engineer of the Belgian postal telegraphs, he said that the Cook and Wheatstone needles that were first introduced in Belgium had been supplanted by the Morse system which was destined to progressively dethrone every other, as it was the acme of simplicity.

In my opinion the grade of skill necessary to successfully operate an automatic system is as high, if not higher than the skill required for the same class of business by Morse, the wear and tear per message upon the automatic operator being greater. The floor space necessary in an operating room to accomodate an automatic system would require to be quite double that for Morse of equal capacity to handle the traffic expeditiously before and after transmission, a very serious matter in large cities.

The automatic system involves the consumption of large quanties of very expensive and special paper for both preparing and recording, not required by the Morse, and the first cost of maintenance and management of automatic machinery for all known or proposed systems is much greater than for Morse.

The difficulty of securing prompt explanation or corrections between automatic stations has been a most serious drawback.

The Wheatstone electro-magnetic recorder survives all the faster chemical systems, because it preserves a permanent ink record, and possesses a greater working margin upon the wires under existing conditions, and is capable of being worked duplex.

There will be large loss of wages through the idleness of employes during an interruption to the wires from storms or other causes upon an automatic system normally worked to full capacity.

Mr. Craig, in his pamphlet on machine telegraphy August, 1888, among other things that he had dressed up in his most attractive style to allure capitalists or the government to buy his system, advocated the use of his keyboard perforators, by patrons of the new system, to prepare their own messages, and send them to the general telegraph office, where they would be transmitted at the rate of from 500 to 2,000 words per minute, and if their correspondents' clerks or typewriters at the distant city can translate the telegraphic characters, the slips would be directly delivered to such correspondents and the cost would be but little more than the government would charge for a specially delivered letter.

This is the most attractive feature that so far as has been urged by the advocates of automatic telegraphy, and it has appealed powerfully to both the non-technical public and to those paternal members of the government and congress who seem to think that the public greatly needs to have its letters carried by telegraph, and that a machine that will shoot 3,000 words per minute will accomplish the object at nearly postage rates. Here we are compelled to depart from the results of experience, to probabilities founded upon experience.

A large merchant in attempting to carry out Craig's plan would need a combined perforating machine and typewriter so that the letter-message being copied from the stenographer's notes for telegrapic transmission would be simultaneously prepared on the automatic slip and copied by the typewriter for the files, and also for the patron to see what he was sending away. Every error of the clerk in copying from the stenographer's notes or in striking wrong keys, would necessitate cutting and patching the automatic tape or leaving it with a jumbled up mess of errors and corrections to go over the wire. The clerk must be as highly trained as Wheatstone punchers with years of daily training in order to copy 720 words per hour on an average of messages averaging 30 words each, and at this rate the shorthand characters must be as readable as the writing in ordinary messages.

The prepared tapes must be upon reels ready for the transmitter, and sent to the central station by letter carrier or messenger, and it is not likely that important messages would merely be thrown in the reel receptacle at such station with thousands of reels from various firms. Each reel must have an address upon it so the central station could tell where to send the message, and only messages for one place could go on one reel.

The distant central station must have clerks to decipher the addresses of every message upon the tapes and place those for each person or firm on a separate reel properly addressed. These reels are delivered to the proper parties by letter carrier, and clerks are set to work to translate the characters into English upon the typewriter which can be done at an average of 900 words per hour by a clerk equally as skilled as a first class Wheatstone copyist trained by years of practice, provided the characters on the tapes were as easily deciphered as those employed on Wheatstone. If patrons desired to maintain secrecy by the use of a cipher code it would slow down the work many times, as any practical mind will readily understand.

The machines used to prepare and record the messages in the sender's office would be very complicated and costly, not less if made in large lots than $150 to $200 each, and a patron doing a large business would need several of them, together with high priced clerks to operate them, and in his correspondent's office at the receiving end one clerk would be required for every 900 words per hour to translate and copy the morning telegraphic nail, to say nothing of the desultory reels that would arrive during the day.

In the event of an interruption to the wires during the night, the messages would encroach upon the day service and cause great confusion. Of course when long letters were transmitted, the above rates of preparing and copying could perhaps be doubled in the case of highly trained clerks, but taking the thick with the thin, the figures given I am convinced would be found n actual practice to be too high, just as no telegraph company at present realizes a daily average transmission of 98 30-word messages per hour per sending operator upon the busiest circuits.

It is obvious that the central stations could not keep a lot of dle clerks and machines to come to the rescue of the patrons to ake care of irregular matter or to fill in the absence of their sick or tardy clerks.

Increasing the means of quickening and cheapening the transmission of messages is not followed by a general and proporional increase in their number. This is the experience of all ountries including England where the governments have asumed to do the business at low rates. Any large increase to the number of messages transmitted under the stimulation of lower ates has been found to pertain to the regular class of commerial institutions and firms of the country and the newspapers hat do the great bulk of telegraphing.

It is very uncertain to what extent the public would withdraw ommunications from the mail and transmit them by telegraph. do not believe the amount would be very considerable, even if he telegraph processes were such as to admit of extremely low olls, as letters are absolutely confidential and are largely in such hape for account and record purposes that no electrical transmission and reproduction is possible.

To sum up I think it has been shown that there is a traffic imit to the availibility of an automatic system of about 163 words per minute for ordinary telegrams in one direction; that will cost over twice as much to prepare a given number of rdinary telegrams for automatic transmission as it will to send hem by Morse, and it will cost over twice as much to record hem on the typewriter by automatic than by Morse, provided he operators are paid according to their respective grade of kill.

Inasmuch as commercial exchanges and large business concerns nsist on quick delivery during the business hours of the day, the se of any automatic system for such traffic has been absolutely ut of the question. The public demands for prompt transmission as compelled a constant increase of Morse wires worked either ngle, duplex or quadruplex, which during the night afford more arrying capacity by Morse method than it is possible to get business to fill at remunerative rates. The cost of managers, chief operators, operators and clerks is about 44 per cent. of the total expense of transacting a general telegraph business, under the most economical management. So that if it were possible to prepare, transmit by automatic system and copy for delivery during the night, large batches of mailable matter at a price that would about pay for such preparation and delivery, the tolls for the commercial day work would have to be high enough to bear the entire 56 per cent. general expense of the whole telegraph system besides depreciation and interest on investment.

Dr. A. E. Kennelly:—The question of rapid telegraphy has two aspects, the engineering and the commercial. I suppose that we may assume as a purely engineering problem, that any desired speed over a thousand mile circuit can be attained up to 2,000 words per minute, provided that expense is no object. That is twice as high as the speed which Mr. Jones tells us has actually been reached between New York and Chicago. The paper before us suggests a particular means of carrying out a speed such as this, viz., a method based upon the use of an automatic current transmitter, with special tape and contact devices, and also upon the use of a special form of receiver. I do not think that the particular kind of transmitter and receiver suggested in the paper is of any consequence to the general problem. In the first place, it is not necessary, so far as I can see, to employ an alternating-current transmitter. That is only one form out of a number of forms that have been devised. It is not necessary to employ a photographic device of the type described, because that is a difficult instrument to handle and it must evidently require considerable skill. Moreover, I should suppose it would place a large amount of inductance in the receiving instrument. In such work as I have done on apparatus employing polarized light, I have generally found that a large amount of magnetic force was required, a great number of ampere-turns, and that suggests a high inductance at the very worst place in a high-speed circuit to receive it, namely, at the receiving terminal. Still it is interesting to see that the authors have been able to secure records of very high speeds, and as an experimental investigation it is, no doubt, a very interesting matter, though as regards actual practical telegraphy I should think that some modification of the Bain instrument would be very much simpler to construct, operate and introduce.

The commercial question is, of course, the one which controls in this matter. If you have a very high rate per word you will, of course, have a very small number of messages. If your rate is, say, a cent per word, then it is a matter of general experience, that if you make the rate just one-half a cent per word, you will not get, at the outset at least, double the traffic, no matter what it has cost you to improve the system to accomodate the increase of traffic. That has been true in cable and in land telegraphy.

I do not say that you will not ultimately get the increased traffic —I think you will—but in the meantime, while the experiment is being performed, you have to face a loss of income. At the present rates of telegraphy only important communications can be commercially sent. We do not send letters that way because it would be too expensive. I do not think there would be any doubt, if we got in the habit of writing our letters by telegraph, that the telegraph people would eventually find means to handle the traffic which would result. I do not believe that they would continue to do so, in that event, by merely reduplicating Morse circuits. I do not doubt that when they had to handle many times the traffic that they have now they would continue to handle it by other means than by the ordinary Morse system. A time would come when the reduplication of Morse circuits and operators would be so great that they would find it to their advantage to introduce an automatic system. Just when that time will come, of course, I cannot say. It has been the experience hitherto that when the traffic exceeds a certain rate, the Morse system has been unable to deal with the traffic, and an automatic system has been adopted. The automatic system used has been the Wheatstone system. If the traffic were again increased in corresponding ratio, however, even the Wheatstone would be unable, no doubt, to meet the demand, and a still more rapid system would be called into existence. But I still believe that if the necessity existed, that if we were accustomed to send our mail through the wires, the telegraphic system would readjust itself so as to handle the business. Commercially, the telegraph system might at first be placed at a considerable loss, because the public would have to do their own punching and translation, and this education of the public is a slow and expensive process. Whether we shall see it in the future is a matter which only the future can tell. It is a grand possibility that we could send our letters to a telegraph office and get them sent over the wires instead of waiting for the locomotive to carry them. It is only a question of time and commercial necessity when it shall become accomplished.

MR. P. B. DELANY: It is always interesting to a telegrapher to hear from Mr. Jones, especially in a historical way. His resumè of the telegraph is always very entertaining. I presume from his standpoint of a Morse telegrapher that he aims to be perfectly just and fair. Before referring to the paper which is up for discussion I would like to review in a very brief way some of the statements advanced by Mr. Jones regarding the telegraph both from a practical and a commercial standpoint. He goes back to 1857 and the 60's, and quotes the Bain system in its state of development at that period as an evidence that there is no necessity at the present time for machine telegraphy. Everybody who has studied the subject must know that at the beginning of Bain's experiments the chemical paper which he used for recording was evanescent, and would fade out in a few moments, that his perforating machine and all his apparatus was very crude and that in almost every respect his plan was practically inoperative.

To prove that good automatics have no more show than poor ones, Mr. Jones then goes to the Wheatstone system and does it certainly full justice in regard to its merits of speed. I have watched the Wheatstone system in England personally for a long time, and, while the speed Mr. Jones refers to may be obtained on special occasions and under special conditions, I am prepared to state that in its practical operation it falls at least fifty per cent. below the speed he has ascribed to it. As to the accuracy of the Wheatstone system or of automatic telegraphy in general he rather impugns it, and says that it is not as correct and reliable as sound reading. I would remind Mr. Jones that where speed is not the main consideration, as, for instance, in cable telegraphy, the Wheatstone system is used and preferred on account of its accuracy. There is no class of telegraphy that requires the same degree of accuracy, or makes a greater demand upon reliable and capable operators, owing to the fact that the messages are composed almost exclusively of code words or of cipher, having no text to guide the operator, the alphabet being as it were, thrown together promiscuously like pied type. In every instance, with the exception of three cables crossing the Atlantic, out of the eleven that are in operation, the Wheatstone system or some system similar to it, with slight modification, is used, and yet with the exception of one or two cables, operators are able to transmit as fast by hand as the cables will take it, but nevertheless the Wheatstone system is used because of its uniformity in signaling to which higher speed is incidental. Even the business transmitted from London to the cable stations is sent by the Wheatstone system. And as regards the difficulties of translation from the tape, compared to the ease with which translation is made from a sounder to which Mr. Jones refers, the leading cable company, the Anglo-American, punches the messages from the received Wheatstone tape at Valencia without any intermediate translation by typewriter or manuscript. Having spent several weeks at the latter station conducting some experiments I had ample opportunity to study the operations of this system under most trying circumstances, and was informed by the operators that they would much prefer to compose messages on the tape or re-transmit by hand into the cable from a Wheatstone tape, than from the manuscript of their brother operators.

Now as regards the post office business in England, and the deficit which Mr. Jones says accumulates from year to year, it is well understood in England at least that the post office and telegraph departments do not agree in regard to the manner in which the accounts of the two departments are kept. But assuming that the post office department did justice to the telegraph department, Mr. Jones neglected to state that there is a large volume of railway business—I will not state what proportion it bears to the whole—but I might venture to state that it represents at least five or six per cent. in value which goes free. And furthermore that the charge of one shilling for 75 words during the day, and 100 words for a shilling at night and twopence for drop press messages, is only made possible by the use of the Wheatstone system, and, if the rate charged for press work in England approximated the charge in America, together with the free railway business, if it was charged for, the British telegraph whold be self-sustaining if not profitable.

Mr. Jones next comes to automatic telegraphy in America. I was connected with the experiment between Washington and New York that he refers to, and 500 words a minute were transmitted. We thought at that time and we were justified, considering the state of the art, that the signals were very good, especially in face of the fact that the then electrician of the Western Union Telegraph Company staked his reputation on the statement that it was impossible to send more than 60 words a minute over, I think, 100 miles of line. Mr. Jones with his experience certainly understands that improvements or innovations, as you might call them, have never been welcomed by the controlling telegraph company, that the duplex had a long battle before it was adopted by the Western Union Telegraph Company, and its inventor had to create an opposition telegraph line for the purpose of forcing it upon their notice; that the quadruplex system of which he speaks so favorably, even after the Western Union took it over, was held in abeyance for weeks until the managers of the company told the operators that unless they worked the system they would get others who would, that is, in other words, if they did not *make* it work and lay aside their prejudices they would be dismissed. That is the history of the quadruplex system, and yet according to a statement of the president of the Western Union Telegraph Company, five or six years ago, if the artificial circuits created by the quadruplex system had to be reproduced in the actual wires, or the facilities that they afforded had to be duplicated, it would cost the company eleven or twelve million dollars.

Coming back to the automatic system of the original automatic company in this country, Mr. Jones says it lived its natural course and then died. I know what became of that company. A telegraph magnate of the time paid one man connected with it who had a basis or foundation patent in his own name, and unassigned to the company $120,000 for it, after having agreed to pay the automatic company about $3,000,000 for the system, which he failed to do, and that same system was turned over to the Atlantic and Pacific Telegraph Company, or the Western Union Telegraph Company eventually, for between three and four millions of dollars. Not such a bad investment for a system that was not good. I am quite familiar with all of Mr. Craig's statements and claims for automatic telegraphy, and I think Mr. Jones will agree with me that no telegrapher in this country or any other ever accepted Mr. Craig, from whom he quotes so copiously, as a technical authority in telegraphic matters, nor did Mr. Craig claim it. The American Rapid Telegraph Company, which was the last automatic company in operation in this country, did an enormous business, which, if not profitable, was at least self-sustaining, which was a great deal in view of its limited ramification at the time. It was taken up by a Morse company, and, through stock manipulation in Wall street, swamped, its stock having dropped from $115 one day to $2 per share the next day.

Mr. Jones next refers to the use of the Wheatstone system in this country, and cites some speeds between here and Chicago, which are certainly very creditable to the system, and he puts against that work, speeds reached by the Morse system between here and Pittsburg. The Wheatsone system employs automatic repeaters between New York and Chicago, while Pittsburg by the Morse system is reached direct. The Morse operators for this demonstration were undoubtedly the most expert to be found in America, while it is a noted fact that the Wheatstone system in this country has, through the policy of the company using it, been largely handicapped by inefficient and ill-paid labor. It would have been fairer if Mr. Jones had given notice of a race and not chosen his own time and conditions.

In regard to automatic telegraphy in general, I admit that the present companies have all the facilities necessary to carry all the business they can get at the present rate with their slow hand methods of operation, but it does not follow from this that the lowering of the rate, so that four or five times the number of words could be sent for about one-half the price would not increase the business so as to render necessary an automatic system of telegraphy and yield very profitable returns.

I will not take the time of the meeting to go into an analysis of Mr. Jones's calculation regarding the difference in labor and the number of people employed in the two systems relatively. That I will do at some later day; but I will make this statement, and I think it can be substantiated: That an operator preparing a message on a tape perforator without any interruption from line or other causes, the operation being purely local, will maintain a speed averaging as high as the Morse operator will average sending by hand, and that an ordinary wire from New York to Philadelphia will deliver a perfect record of 3,000 words a minute, and that a one-ohm-per-mile line will deliver a perfect record of 1,000 words a minute between New York and Chicago, and that when these messages are received, type-writer operators will translate from the tape bearing these machine-made characters, unchanging in their characteristics, with greater accuracy and speed than from their own notes, or about as readily as from print, and everybody knows that an ordinary typewriter operator will easily translate 35 to 40 words per minute. Now, in the case of the Morse receiver, using the typewriter he cannot translate from sound any faster than the Morse operator will send, and Mr. Jones I am sure will not say that any Morse operator can keep up a speed of 35 to 40 words a minute on a average all day. I consider that a typewriter translating from a tape of distinctly recorded characters is equal to two Morse receivers, and that in the operation of the automatic system one employe out of three is saved, from an economical standpoint. The introduction of perforators into business houses doing a large amount of business for the preparation of their own messages, and the translation of their messages at the distant end of the line is but a small feature of what is practicable in connection with machine telegraphy. It does not imply that the bulk of the business will be done in this way. The aim of an automatic telegraph company for carrying a large number of messages at a low rate is simply to take the place of the mail train. Messages may be sent to the central office in the city either by the post office or by special messenger. They are to be transmitted at a high rate of speed, and dropped into the post office at the distant station, typewritten, put in envelopes and stamped just as if they had come by mail. I cannot see from a commercial standpoint where the hardship is in being compelled to supply perforators and translators at the ends of a wire necessary to handle all the business the wire will carry. I should be very glad if I was in the business commercially to be able to make one wire keep 500 perforators and translators busy. It obviates great expense in the construction of the original plant, in the number of wires that you have to construct; in the size of the poles necessary to carry them; the difficulties of tree trimming, and so on. And, more than all, the entailed cost of maintenance, which amounts, I think, to about $4.00 per year per mile per wire, according to the best information on the subject, and when you consider that one wire worked at an automatic high speed is equal to 20 wire quadruplex, and 40 duplex and 80 to 100 simplex for long or short distances, it seems to me there is room for great economy, and, consequently room for a very low rate of transmission, so as to take from the mails a vast amount of business that now goes by the mail train. And yet the chief objection of the Morse men is that one wire can be made to keep so many operators going.

Mr. Jones makes a point of the delay. He says that in Chicago there is on an average a delay of 16 minutes and at New York a delay of 15 minutes by the Wheatsone system, making 31 mintes delay in the transmission of a telegram from New York to Chicago. Now, we have all had experience in telegraphy to the extent of paying for messages and having them sent and delivered. I venture to say that the average time of telegrams in this country, leaving out the business done between stock and other commercial exchanges, will average more than an hour. The telegraph companies in this country are very careful not to put on the message that you receive, the time at which it was filed at the point from which it started. They give you very plainly the time at which it was received at the office down the street. That is simply a tab on the messenger to see whether he stopped to play marbles on the way. But if you receive a telegram at six o'clock this evening from Philadelphia, there is nothing to show you that it was not filed there at nine-o'clock in the morning. If we take Mr. Jones's statement, messages are only a few minutes on the way, but every telegraph operator knows that messages accumulate and hang on the hooks for hours at a time, especially in the case of interruption to some of the wires, and that the traffic chief goes around and sorts them over perhaps a dozen times, picking out the more important ones to get them off first, so that if a man telegraphs his wife that he will be home to dinner at six o'clock they endeavor to get that message to his house a little before he arrives, while the wife of the man who says he won't be home till morning, sits up half the night waiting.

Now, if I may be permitted a few words in regard to the paper before the meeting. Prof. Crehore and Lieut. Squier advance the theory that much is to be gained from the use of the alternating current in telegraphy, and naturally enough I presume most people are inclined to accept that proposition. But, referring to the description, it seems to me that the object sought is not gained in the plan proposed, for the simple reason that if a half-wave, we will say, at any period, but taking it on the basis of 140 whole waves to the second, is eliminated for a dot, or for a space, two half-waves for a dash, and three half-waves for spaces between words, and so on, I am unable to see how by the elimination of half-a-wave or three half-waves you get the benefit of the alternation, because the next impulse that goes into the line is of the same polarity as the one preceding, and the line with its static capacity remains charged. especially at the receiving end. It may be said that there is a drop in the potential to the zero point which possibly allows the line to clear itself to a certain extent, but I think no one will claim that the effect of that is of paramount consequence compared to the amount of current remaining in the distant end of line while this half-wave is being eliminated. Furthermore, unless absolute synchronism is maintained between the movement of the tape on the wheel under the transmitting brushes and the alternations of the current, the signals will be clipped or false signals sent, which would not be the case with a constant current. It may appear to be a very easy matter to some, to subject a tape to the preliminary operation of making a uniform row of guide holes so that it may be pulled through a punching machine afterwards, which, by the operation of a star wheel fitting into these guide holes, will feed it absolutely correct for the composing of the dots and dashes on the tape by another operation. This does not appear to be a simple matter to me, and I have had some experience in that line; but assuming that it was easy to do, when this message is put on the wheel for transmission there must be some slack or else considerable tension on the strip to hold it in place, and the star wheel pulling the tape over the circuit wheel where the transmitting brushes rest, surely will have a tendency to pull it and spread the guide holes especially if the friction of the transmitting brushes is of any considerable amount, and if the friction is not sufficient to hold the tape it would be, I think, mechanically impossible to pull that tape at a high rate of speed so that the dots and dashes would conform accurately to the reversals of the current. Then there is the other very important consideration of the wheel becoming coated with dirt and not making a good contact. There is the difficulty also of making dashes with a perforator; such a machine would be altogether a very intricate affair. Thus far all efforts have failed to make a perforator of this kind, that would do its work accurately and reliably. The same objection of lack of true alternation of current applies in regard to the use of condensers, which I believe the paper states might be introduced in series in the line. The condensers would not be uniformly discharged.

Perhaps I do not understand the operation of the receiver proposed or contemplated in the paper. I presume that two pens must rest on top of the chemical paper, one connected to the line and one to the earth, and, as the currents are normally alternating, it must be that in the case of a dash, for instance, one portion of the dash will be formed on one line and the other portion on the other. As it takes a complete wave of the current, and as the record will be made in the negative, I think that such a record would be very difficult to translate. Furthermore, the tape would have to be placed on the transmitter, while the transmitter was at rest, and it would have to be fixed so that if there was to be any uniform relation between the signals as regards the character of the current that was to begin the message, it would have to be fixed very accurately on the star wheel that was going to pull it. Even then I am unable to see how signals could be depended upon for alignment. Take the letter *w* for instance. The dot of the letter would be on the top line, the half of the dash would be on the lower line, and the balance of the first dash would be on the top line again, and then another complete wave for the other dash would cause similar changes in position.

In regard to the speed claimed in the paper, I have no doubt that the computation, was the result of inexperience, when it states that the word "ten" may be transmitted 1,200 times in a minute.

The word "ten" is composed of four signals. A dash for the *t*, a dot for the *e*, and a dash and dot for the *n*. These four signals might be sent by the most economical use of perforations such as is used in another system with four impulses. The average number of impulses to a letter is about three. If you count the spaces between the letters, or between the component parts of a letter, it gives considerably more, and the average number of letters to the word in the English language is about five. So that the word "ten" comes to very little more than the impulses comprised in one letter; or, making all allowances, it seems to me that the speed reached or supposed to be possible in this arrangement would amount to about 300 words a minute instead of 1,200. According to the continental code there are in the alphabet 44 dots and 38 dashes. The paper proposes to allow the length of two dots for a dash. In the Wheatstone and other systems three lengths are allowed and I think practice will show that it is not too much. Now on that basis this system, compared with the strip using a single dot for a complete dash, as well as for a dot, or where all the signals are dots, it seems to me that the number of impulses required for the same amount of transmission would by this system be almost double.

Regarding the duplex and diplex extensions of this system, I am unable to grasp the solution advanced in the paper. I can understand that predetermined subdivisions of the circuit wheel might give off on electro-magnetic instruments of some kind operated synchronously different messages, but I do not see how it would be possible to have the division of this wheel predetermined by messages of undetermined arrangement of dots and dashes, and any of the currents used for lesser speeds must be of necessity, as I understand it—unless they are superposed, and I do not suppose that was intended here—be taken from the higher rate of speed, and the maximum rate of speed must be deteriorated in a corresponding degree. I cannot see how two messages can be simultaneously received on a chemical system, for the simple reason that all the impulses will manifest themselves on all the tapes of the receivers. (Applause.)

LIEUT. SQUIER:—I will only take a moment, as the hour is so late. It has been a pleasure to us who are inexperienced in business methods to hear what Mr. Jones has said this evening. The experience gained in actual practice is of course very much to be valued, and he seems to have succeeded in showing, I think, that from the beginning there was a desire to increase the capacity of lines; in other words, that the telegraph companies found that men at the ends of the lines were less expensive than wires. And I judge from the arguments that have been put forth that we have now about reached a point at which we have gotten all the speed that is desirable, and all the business can now be handled in the present way, and that, so far as we can draw from the data he gives, we have practically reached a limit in telegraphy. Mr.

Jones says that the telegraph companies can handle all the business now offered to them. This is probably true of the particular kind of business that the telegraph companies are now handling; but that is not the kind of business we were particularly considering in this paper. Undoubtedly Mr. A. will continue for some time to come to send his ten words to Mr. B. as at present, and the existing companies will continue to handle that kind of business. The business we were speaking of was more particularly telegraph letter writing—less urgent matter perhaps, but still, more so than ordinary letters—and this larger volume of business we think can only be handled by some form of automatic transmission. We know that plenty of people pay ten cents for a special delivery stamp so as to gain an hour perhaps in the delivery of a letter at its destination. Now that is just the kind of business that we are talking about—not the long letter of friendship or the ten word message, but the business letter which we desire to reach our correspondent in Chicago, for instance, not in fifteen minutes, but within two or three hours. That is the kind of business—the new business, that we were talking about. Therefore, the arguments that have been presented do not seem to me to hold, because the speakers have been talking about a kind of business that we do not propose to handle at the outset.

I am sorry that Dr. Kennelly should have gotten the idea that we require the use of a polarized receiver. We used it in our experiments because it was found convenient to investigate the properties of rapidly varying currents, and we did not propose it in a practical telegraph receiver at present, and so state in the paper. Dr. Kennelly also suggests that when the demand for such business arises, the telegraph companies will be able to handle it. The way to create that demand is to put down the rates so that business people can telegraph that kind of business. If the rates are kept as they are now, probably that demand will not arise, but I think if the rates were half what they are or even less than they are, the demand would be enough. So that it seems that the fact is that the people must be educated up to the service they are entitled to, and then the companies will be obliged to take care of the business as soon as the demand comes. The better way to do is to put the price down.

There has been very little discussion of the engineering side of the paper which we had hoped for, and there seems to be no question about the transmission of an adequate number of waves. We have several examples of this already accomplished in the Anderson and other systems, so that there is no question about the practicability, but we believe this particular system has elasticity and development not possessed by the others, and we are in hopes that this point will be more fully brought out as an engineering feature aside from its commercial side.

In regard to transmission of waves, it might be said that the long distance telephone line which is now in practical operation is about as good an example of the transmission of waves as could be wished, and beside which the system we propose is of course very simple. When we can distinguish the voice between here and Chicago, this is an example of wave transmission which is much more complex than anything we have proposed.

In regard to diplexing the line and so on, which Mr. Delany says he does not understand, I think the paper when examined carefully, clearly shows how the punching should be done. Our experiments were actually carried out, and the diplexing and so on have actually been done. I might mention something that has only developed in the last few days. We never until a day or two ago used the cutting out process at definite intervals on currents of considerable volume, but we have just made some further experiments, in this direction and found that there is no trouble at all. In fact, on this circuit we used an alternating arc, and found it very convenient as a receiver, and I have a record here of messages sent through an alternating arc at the rate of 280 alternations per second. The arc appears all right; nothing is happening to it, so far as the eye can see. Of course the alternations are so rapid that the eye would not notice them. I have here the records, which anyone can look at and see how perfect they are (Exhibiting). This was an ordinary street arc-lamp. I merely mention this to show an additional feature of the matter, that you can synchronously interrupt and suppress integral waves in circuits carrying considerable power, the current being in this experiment about ten amperes.

DR. ALBERT C. CREHORE:—The commercial interest in this subject is undoubtedly very great, and it is impossible to refrain from some remarks bearing upon that, but where any part of the physical portion of it is misunderstood, I very much desire to have that corrected. I want to speak particularly in regard to Mr. Delany's not understanding the use of the half wave. First, in regard to the alphabet. The one shown was only one of very many which can be used. It is hoped that some time later on we shall be able to give more definite information as to the particular form of machine, but the distinction between this alternating wave and the dot made by the direct current seems to lie in the fact that the electromotive force is not a constant degree, but is increasing. I do not mean to go into the complicated physical question at all, but it seems to me that all the objections that could be brought against it were answered by the first speaker in saying that these waves can be transmitted. I very much wish that Prof. Pupin, who has some knowledge of this from his own experiments, would add something to this discussion.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, May 18th, 1897.

The annual business meeting of the Institute was held this date at 12 West 31st Street, and was called to order by President Duncan at 4 p. m.

The following associate members were elected at the meeting of the Executive Committee in the afternoon.

Name.	Address.	Endorsers.
Banks, William C.	Electrician, Gordon-Burnham Battery Co., 82 West Broadway, New York City.	Geo. T. Hanchett. Chas. D. Shain. E. V. Baillard.
Clement, Edward C.	Ass't Examiner, Electrical Division, U. S. Patent Office, Washington, D. C.	S. D. Field. R. W. Pope. F. A. Pickernell.
Davidson, A.	Cable Engineer and Electrician, Central and South American Telegraph Co., Lima, Peru.	Jos. Wetzler. T. C. Martin. R. W. Pope.
de Redon, Constant	Consulting Engineer, 27 Thames St., New York City,	Max Osterberg. Wm. Maver, Jr. W. A. Anthony.
Hosmer, Sidney	Sup't Underground Cable Dep't, Boston Electric Light Co., Ames Bldg, Boston, Mass.	W. A. Anthony. W. R. C. Corson. I. H. Farnham.
Kinsley, Carl	Teacher of Electrical Engineering, Washington University, St. Louis, Mo.	G. F. Durant. H. H. Sykes. Fred'k Bedell.
Neilson, John	Sup't of Interior Wiring Department, Larchmont Electric Co., Larchmont, N. Y.	F. A. Pattison. A. J. Farnsworth. R. W. Pope.
Richey, Albert S.	Electrician, Citizens' Street Railway Co, 403 W. Adams Street, Muncie, Ind.	H. B. Smith. C. P. Matthews. W. E. Goldsborough.

Total 8.

TRANSFERRED FROM ASSOCIATE TO FULL MEMBERSHIP.

Approved by Board of Examiners May 17th, 1897.

Nicholson, Walter W. General Supt. Central New York Telephone and Telegraph Co., Syracuse, N. Y.

RICHARDSON, ROBERT E. Electrical Engineer, Pierce and Richardson, 1409 Manhattan Bldg, Chicago, Ill.

ROSA, EDWARD B. Professor of Physics, Wesleyan University, Middletown, Conn.

Total 3.

The President appointed Dr. M. I. Pupin and George A. Hamilton as tellers, and William J. Hammer and Charles S. Bradley as Proxy Commitee.

The following reports of the Council and Treasurer were read and accepted.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

REPORT OF COUNCIL FOR THE YEAR ENDING APRIL 30TH, 1897.

In accordance with the Constitution, the Council presents for the information of the INSTITUTE a report of its work during the past year.

Under the requirements of the laws of the State of New York, under which the INSTITUTE was incorporated in 1896, the presence of a majority of the Council is required at each meeting to form a quorum. In a national organization, as the INSTITUTE is, the geographical distribution of the members of Council is such, that it is difficult to secure a quorum, ten out of twenty-one being residents of cities at a distance from New York where the Headquarters are located. For this reason an Executive Committee of seven members was appointed in order to properly conduct the affairs of the INSTITUTE. Under this arrangement there have been held since the last report, ten meetings of the Executive Committee.

The necessity of fixing upon a standard of light, was brought to the attention of the INSTITUTE early in the year by representatives of different companies engaged in the electric lighting business, and also by the National Electric Light Association through Dr. Louis Bell, Chairman of a Special Committee appointed by that organization. The matter was referred to the INSTITUTE Committee on Units and Standards, and its report recommending a standard of intensity and method of measurement, was printed in the February 1897 issue of the Transactions.

The amount of $2,300 having been received for life memberships since the founding of the INSTITUTE, and used in the current expenditures, it was decided that the Treasurer set apart each year the sum of $500 to be invested in a compounded membership fund. As the net income of the past year will permit of this being done, the required amount may be set apart from the surplus.

In the course of the business of the INSTITUTE, certain transactions have been made through its office, which are strictly commercial, and have heretofore been accounted for in the yearly report of the Secretary. In order to separate these items more distinctly from the regular receipts and expenditures, the sum of $150 was transferred from the Treasurer to the Secretary for commercial purposes, which includes such matters as the buying and selling of electrotypes, badges, certificates, etc.

The lease of the rooms occupied by the INSTITUTE, at 26 Cortlandt Street, was renewed for another year, the quarters having proved convenient and accessible for home members as well as those visiting the city, and suitable for the holding of committee meetings.

At the March meeting of the Executive Committee, it was voted to hold the General Meeting of the INSTITUTE at Eliot, Me., beginning on July 26th, 1897.

The special Committee appointed last year for the preparation of a new design for the INSTITUTE badge, has fixed upon a design, and prepared a model which has been referred to this annual meeting for consideration.

The total membership at the close of last year's report was 1035, classified as follows:

Honorary Members	2
Members	333
Associate Members	700
Total	1035
Associate Members elected, May 1st, 1896, to April 30th, 1897	103
Total	1138

Resignations have been received during the year, and accepted from the following members as in good standing:

CHARLES E. CHINNOCK,
ADAMS D. CLAFLIN.
WM. J. HISS, JR.,
WM. B. LESTER,
GEO. W. STOCKLY,
EDMUND V. COX,
W. D. MAC QUESTEN,
CHAS. W. SPICER,
S. P. DENISON,
B. P. FLINT,
W. S. FRANKLIN,
W. H. PEIRCE,
ROBERT WATSON,
S. W. ROESSLER,
W. C. BRYANT,
E. E. BARTLETT,
A. S. KIMBALL,
L. A. McCARTHY.

Total resignations 18

There have been the following deaths during the year:

HENRY A. CRAIGIN,
LEVI K. FULLER,
W. T. M. MOTTRAM,
M. B. LEONARD,
H. L. LUFKIN.
SAMUEL C. PECK,
WILLIAM SHRADER,
E. CARL BREITHAUPT,
FRANK H. DORR,

Total deaths	9	
Dropped as delinquent	34	
Elections cancelled	3	
Elected, but not qualified	1	65
		1073

Leaving a total membership of 1073 on April 30th, 1897, (a net gain of 38), classified as follows:

Honorary Members	2
Members	350
Associate Members	721
	1073

A list of the members elected during the year accompanies this report. The names have already appeared in the TRANSACTIONS.

The reports of the Secretary and of the Treasurer, show in detail the financial standing of the INSTITUTE at the close of the fiscal year, together with an itemized statement of receipts and expenses during the year.

SECRETARY'S BALANCE SHEET.

For The Fiscal Year Ending April 30, 1897.

Dr.		*Cr.*	
To balance from previous year	$ 20 20	By cash to Treasurer	$9,953 43
Receipts for the year	9,933 23		
	9,953 43		9,953 43

ITEMIZED STATEMENT OF RECEIPTS AND EXPENSES OF THE INSTITUTE.

For Fiscal Year Ending April 30, 1897.

General Account.

Receipts.

Treasurer's Balance from previous year	$239 99
Secretary's " " " "	20 20
Entrance Fees	475 00
Life Membership (Carl Hering)	100 00
Past Dues	535 23
Current Dues	7,844 95
Advance Dues	45 23
Electrotypes Sold	35 04
Transactions Sold	339 55
Transactions Subscriptions	193 40
Advertising	88 50
Received for Binding Transactions	45 59
" " Badges	41 00
" " Certificates	22 00
" " Congress-Book	27 85
Reprints Vol. 4	136 00
Miscellaneous	3 89
Total,	$10,193 42

Expenses.

Repairs	$1 00
Notary	50
Chicago Meetings	23 15
Library	11 14
Ice	23 30
Commercial	186 26
Laundry	8 25
Office Expenses	17 76
Office Fixtures	24 73
Express	70 53
Telegrams	3 39
Stenography and Typewriting	787 10
Stationary and Miscellaneous Printing	530 57
Postage	496 18
Messenger Service	5 55
Salary Account	2,708 33
Meeting Expenses	215 98
Rent of Office and Auditorium	1,100 00
Engraving and Electrotyping	202 60
Publishing Transactions	2,412 29
Paid for Badges	66 00
Paid for Certificates	9 75
Entrance Fee Returned	5 00
Treasurer's Balance to next year	1,284 06
Total,	$10,193 42

Commercial Department.

Receipts.

Cash from Treasurer, Nov. 23, 1896	$150 00
Sales to May 1st	37 39
	$187 39

Expenses.

Purchases	$25 32
Balance Cash on Hand	162 07
	$187 39

The outstanding current bills against the Institute, April 30, amounted to	$465 55
Due the Institute and collectible probably	655 00

Property on hand according to inventory, May 1, 1897.

Office furniture and fittings	$212 48
Catalogue Type, Cases, etc.	259 75
Transactions on hand	2,803 50
Congress Books	784 50
Library	200 00
	$4,260 23

Of the above, there has been purchased during the year, office fittings amounting to $24.73 and type and type cases for catalogue $259.75. The inventory has been made at a low valuation and does not include the Transactions of 1896.

TOTAL NET ASSETS.

Building Fund	$956 48
Treasurer's Balance, Mercantile Bank	1,284 06
Secretary's Commercial Fund	162 07
Property as per inventory	4,260 23
	$6,662 84

Respectfully submitted for the Council,

RALPH W. POPE,
Secretary.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, May 18th, 1897.

TREASURER'S REPORT.

FROM MAY 1, 1896 TO MAY 1, 1897.

GEORGE A. HAMILTON, TREASURER, in account with
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Dr.

Balance from May, 1896	$239 99	
Received from Secretary, May 1, 1896 to May 1, 1897	9,953 43	$10,193 42

Cr.

Payments from May 1st, 1896 to May 1, 1897, on warrants from Secretary, Nos. 760 to 878, inclusive	$8,909 36	
Balance to new account	1,284 06	$10,193 42
Balance on hand, General Fund, May 1, 1897		$1,284 06

BUILDING FUND.

Balance as per last report	$850 00	
Interest accrued to May 1, 1897, 3 per cent. to May 14, 1892 and 2 per cent. thereafter	106 48	$956 48

Cash book and warrants herewith for audit. Vouchers are in the hands of the Secretary, to whom they are returned for filing after payment.

GEORGE A. HAMILTON,
Treasurer.

New York, May 18th, 1897.

The discussion of the paper read at the meeting of April 21st was then taken up. [See page 130.]

At the conclusion of the discussion, the report of Committee on a new design for the INSTITUTE badge was brought before the meeting, in accordance with the action of the Executive Committee, which had referred it to the annual meeting for consideration. After a thorough discussion of the matter the design reported by the Committee was adopted. [See design on cover.]

The tellers then reported the result of the ballot for officers, which was as follows:

FOR PRESIDENT.

Total Number of Votes Cast........ .348

F. B. Crocker	328
A. E. Kennelly	6
Thos. D. Lockwood	3
E. L. Nichols	2
Jos. Wetzler	2
Carl Hering	1
D. C. Jackson	1
C. O. Mailloux	1
H. A. Rowland	1
H. J. Ryan	1
F. J. Sprague	1
C. P. Steinmetz	1
Total	348

FOR VICE-PRESIDENTS.

Total Vote Cast................. 1334

A. E. Kennelly	431
D. C. Jackson	418
C. S. Bradley	413
C. O. Mailloux	11
W. D. Weaver	9
Nikola Tesla	5
J. W. Lieb, Jr.	4
Frederick Bedell	3
Louis Duncan,	3
F. A. C. Perrine	3
F. J. Sprague	3
Wm. Maver, Jr.	2
H. J. Ryan	2
H. A. Rowland	2
C. T. Hutchinson	2
B. J. Arnold	2
A. S. Kimball	2
Brown Ayres	1
C. F. Brackett	1
Louis Bell	1
A S. Brown	1
W. S. Barstow	1
C. L. Cory	1
F. B. Crocker	1
C. R. Cross	1
Jas. Hamblet	1
W. E. Geyer	1
John Langton	1
T. C. Martin	1
E. L. Nichols	1
W. B. Potter	1
W. D. Sargent	1
L. B. Stillwell	1
W. M. Stine	1
B. F. Thomas	1
Jos. Wetzler	1
Total	1334

FOR MANAGERS.

Total Votes Cast................. 1755

Alexander Macfarlane	428
Gano S. Dunn	408
Herbert Laws Webb	400
W. F. C. Hasson	399
R. B. Owens	13
Samuel Sheldon	9
M. I. Pupin	8
W. J. Hammer	6
A. A. Knudson	6
C. E. Emery	5
Jos. Wetzler	4
A. J. Wurts	4
Louis Duncan	3
E. J. Houston	3
C. P. Steinmetz	3
W. S. Barstow	2
F. Bedell	2
A. C. Crehore	2
O. T. Crosby	2
Alex Dow	2
H. W. Leonard	2
M. Levis	2
Wm. Maver, Jr.	2
F. A. C. Perrine	2
R H. Pierce	2
A. L. Rohrer	2
C. A Terry	2
C. F. Uebelacker	2
E. G. Acheson	1
Brown Ayres,	1
Wm. A. Anthony	1
C. L. Buckingham	1
J. B. Cahoon	1
E. Caldwell	1

J. J. Carty	1	C. O. Mailloux	1
C. L. Clarke	1	L. B. Marks	1
W. R. C. Corson	1	A. L. Riker	1
Chas. Cuttriss	1	H. G. Riest	1
W. L. R. Emmet	1	E. E. Ries	1
C. C. Haskins	1	C. T. Rittenhouse	1
F. S. Holmes	1	H. J. Ryan	1
A. Hartwell	1	O. B. Shallenberger	1
F. S. Hunting	1	Nikola Tesla	1
D. C. Jackson	1	J. H. Vail	1
W. J. Jenks	1	C. H. Warner	1
S. J. Larned	1	Townsend Wolcott	1

Total.... ....1755.

FOR TREASURER.

Total Votes Cast..................348

G. A. Hamilton	346	Ralph W. Pope	1
W. J. Hammer	1		

Total................. ...348

FOR SECRETARY.

Total Votes Cast...........348

Ralph W. Pope...................348

President Duncan announced the result of the election, and appointed Mr. W. J. Hammer and Dr. M. I. Pupin a committee to escort the newly elected President to the Chair.

The following paper was then read by Dr. Alexander Macfarlane, discussion upon which was deferred until the General Meeting, July 26th.

The meeting then adjourned, the members reassembling at "The Arena," where the annual dinner was held, at which 92 members and guests were present.

A paper presented at the Annual Meeting of the American Institute of Electrical Engineers, New York, May 18th, 1897. President Duncan in the Chair.

APPLICATION OF HYPERBOLIC ANALYSIS TO THE DISCHARGE OF A CONDENSER.

BY ALEXANDER MACFARLANE.

In recent years the theory of the discharge of an electric condenser has played a very important part in the advance of electrical science; for it served as the starting point of the experiments of Feddersen, Paalzow, Helmholz, Lodge, Hertz and many others, which culminated in the demonstration of the existence and properties of electromagnetic waves. The theory of the discharge was first given by Lord Kelvin, then Professor William Thomson, in a paper on "Transient Electric Currents" published in the June number of the *Philosophical Magazine* for 1853. The application to the phenomenon of the principle of the conservation of energy leads to the differential equation

$$\frac{d^2 q}{d t^2} + \frac{R}{L} \frac{d q}{d t} + \frac{1}{L C} q = 0 \qquad (1)$$

where R denotes the resistance and L the inductance of the circuit, and C the capacity of the condenser which is practically the capacity of the whole circuit. If $q = A\, e^{mt}$ be assumed as the solution of the equation, then m must be such that

$$A\, e^{mt} \left(m^2 + \frac{R}{L} m + \frac{1}{L C} \right) = 0$$

which reduces to

$$m^2 + 2\, a\, m + b = 0 \qquad (2)$$

where for brevity a is written for $\frac{R}{2 L}$ and b for $\frac{1}{L C}$.

According to the theory of the quadratic equation, there are two general cases separated by a transition case. If a^2 is greater than b; there are two real values of m, namely

$$-a+\sqrt{a^2-b} \text{ and } -a-\sqrt{a^2-b}.$$

If a^2 is less than b, there are two imaginary values of m, namely,

$$-a+\sqrt{-1}\sqrt{b-a^2} \text{ and } -a-\sqrt{-1}\sqrt{b-a^2}.$$

The transition or separating case is where $a^2=b$; then there is only one value for m, namely, what is common to the two general values.

The following are the solutions which are usually given of the differential equation. In the case of real roots

$$q=c_1\,e^{-(a-\sqrt{a^2-b})\,t}+c_2\,e^{-(a+\sqrt{a^2-b})\,t}; \qquad (3)$$

in the case of imaginary roots,

$$q=c_1\,e^{-(a-\sqrt{-1}\sqrt{b-a^2})\,t}+c_2\,e^{-(a+\sqrt{-1}\sqrt{b-a^2})\,t}; \qquad (4)$$

and in the transition case

$$q=e^{-at}\,(c_1+c_2\,t). \qquad (5)$$

In the imaginary case, the apparently impossible solution is reduced to the form

$$q=A\,e^{-at}\sin\left[\sqrt{(b-a^2)}\,t+\varphi\right] \qquad (6)$$

which shows that the change in the condenser at any time is given by a sine wave of period $\dfrac{2\pi}{\sqrt{b-a^2}}$ and of amplitude which diminishes geometrically at the rate a.

As the limiting case separates the two complementary regions of the real and the imaginary, we expect that the real solution is also capable of reduction to a form analogous to (6) and exhibiting the function with equal clearness. We also expect the transition solution to be evident from the two general solutions; but when they are in the above forms, the transition is not evident. We observe that in the former general case the roots are treated as simple algebraic quantities, while in the latter general case they are treated as complex quantities. A complex quantity consists of two components, one of which is real and the other imaginary. If there is any thorough going analogy, it must be possible to treat the real roots also as a species of complex quantity.

A complex quantity $a+b\sqrt{-1}$ can be reduced to the form

$r\ (\cos\ \theta + \sqrt{-1}\ \sin\ \theta)$; for $r = \sqrt{a^2+b^2}$, $\cos\ \theta = \frac{a}{\sqrt{a^2+b^2}}$, $\sin\ \theta = \frac{b}{\sqrt{a^2+b^2}}$. If we enquire into the geometrical meaning of the $\sqrt{-1}$ here appearing, we shall find that it means a quadrant of turning round the axis perpendicular to the plane of reference. Let β denote that axis, then β^θ denotes an angle of θ radians round the axis β, and

$$\beta^\theta = \cos\ \theta + \sin\ \theta\ \beta^{\frac{\Pi}{2}}.$$

Hence the ordinary complex quantities can be expressed in the form

$$r\ \beta^\theta = r\ (\cos\ \theta + \sin\ \theta\ \beta^{\frac{\Pi}{2}}),$$

and they are simply coaxial quaternions, the axis being commonly left unspecified, as it is the same for all.

Let $s\ \beta^\varphi$ denote another complex quantity, than $r\ \beta^\theta \times s\ \beta^\varphi = rs\ \beta^{\theta+\varphi}$

$$= r\ s\ [\cos\theta\cos\varphi - \sin\theta\sin\varphi + (\cos\varphi\sin\theta + \cos\theta\sin\varphi)\ \beta^{\frac{\Pi}{2}}).$$

Here the product is formed according to the theorem for the cosine and the sine of the sum of two circular angles. Now the circular trigonometry has its complete counterpart in the hyperbolic trigonometry; consequently we expect to find a hyperbolic complex number. This subject was investigated at length in "Papers on Space Analysis,"[1] which I published 1891 to 1894. In this paper I propose to show that by treating the real root as a hyperbolic complex quantity, equation (3) can be reduced in precisely the same way as equation (4).

The exponential expression for a circular angle x is $e^{\sqrt{-1}x}$, which expressed definitely is $e^{x\beta^{\frac{\Pi}{2}}}$. By applying the exponential theorem, we obtain a series which breaks up into two parts, namely,

$$1 - \frac{x^2}{2\,!} + \frac{x^4}{4\,!} - \frac{x^6}{6\,!} +,$$

and

$$\sqrt{-1}\left[x - \frac{x^3}{3\,!} + \frac{x^5}{5\,!} - \right],$$

of which the former is the series for cos x and the latter the series for sin x. Now because the terms of the sine series are all affected by the sign $\sqrt{-1}$, they do not add directly to the other.

---

[1] "The Imaginary of Algebra." *Proc.* A. A. A. S. vol. —, p. 50. Fundamental Theorems of Analysis, p. 23. Definitions of the Trigonometric Functions, p. 30. Principles of Elliptic and Hyperbolic Analysis, p. 17.

terms, but are geometrically compounded as forming a perpendicular component to the terms of the cosine series. We enquire for the analogous exponential expression for a hyperbolic angle x. Algebra furnishes none. It is not e^x, for

$$e^x = 1 + x + \frac{x^2}{2\,!} + \frac{x^3}{3\,!} + \frac{x^4}{4\,!} +$$

and here there is no ground for breaking up the series into two components; all the terms are real, and so add directly. For the same reason, it cannot be e^{-x}. But we know that

$$\cosh x = 1 + \frac{x^2}{2\,!} + \frac{x^4}{4\,!} + \frac{x^6}{6\,!} +,$$

$$\text{and } \sinh x = x + \frac{x^3}{3\,!} + \frac{x^5}{5\,!} + ;$$

there must therefore be some proper way of expressing the sum by an exponential function.

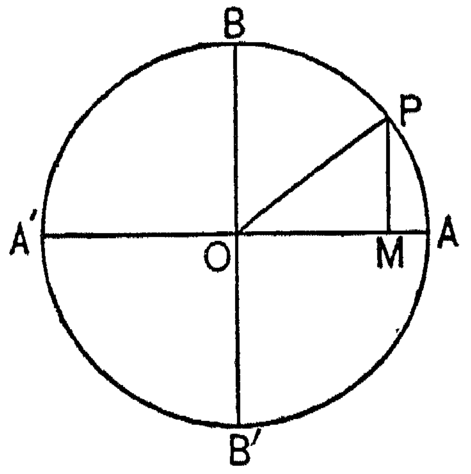

FIG. 1.

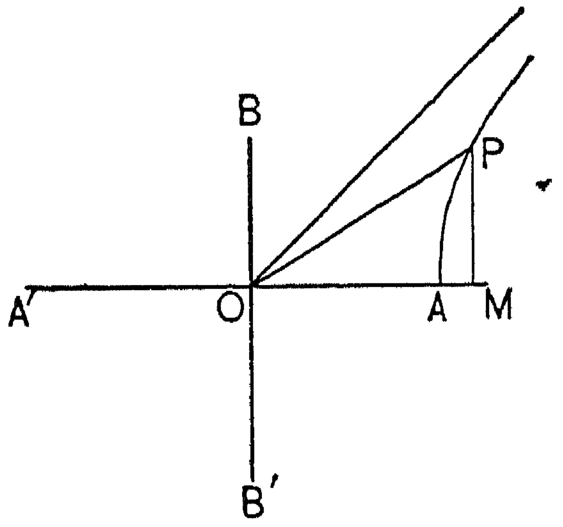

FIG. 2.

Before proceeding further, let us consider what is meant by a hyperbolic angle.

In Fig. 2, let A P be an arc of an equilatoral hyperbola, O A and O B the equal semi-axes. The radius O P is derived from the semi-axis O A by a hyperbolic versor which has a magnitude x and an axis through O perpendicular to the plane. Now x is not the ratio of the arc A P to either the radius vector O P or the semi-axis O A; but the ratio of twice the area of the sector A O P to the square on O A. In the circle, Fig. 1, the ratio of twice the area of the sector A O P to the square on O A is equal to that of the arc A P to the semi-axis O A; the symbol x may denote either. But in the hyperbolic counterpart it is the ratio of the areas which must be taken. If x denotes the ratio of twice the area of the hyperbolic sector A O P to the square on O A, then as a matter of truth, not mere definition, cosh x, by which is meant the ratio of O M to O A, is equal to

$$1 + \frac{x^2}{2\,!} + \frac{x^4}{4\,!} + ;$$

and sinh x, by which is meant the ratio of M P to O A, is equal to

$$x + \frac{x^3}{3\,!} + \frac{x^5}{5\,!} + \quad .$$

We observe that O M and O A have the same direction, while M P s at right angles to O A; hence we conclude that the second series is really at right angles to the first. But instead if $\cos^2 x + \sin^2 x = 1$, we have $\cosh^2 x - \sinh^2 x = 1$; the fact that it is the difference not the sum of the squares which is equal to 1 attaches a scalar $\sqrt{-1}$ before the sinh series. We conclude that the proper expression for the hyperbolic versor is

$$\cosh x + \sqrt{-1} \sinh x \, \beta^{\frac{\Pi}{2}};$$

and that the exponential expression is $e^{\sqrt{-1}\, x \, \beta^{\frac{\Pi}{2}}}$. For brevity we will donate $\beta^{\frac{\Pi}{2}}$ by i. Thus e^{ix} denotes a circular angle, and $e^{\sqrt{-1}\, i x}$ a hyperbolic angle.

The process by which equation (4) is usually reduced to equation (6) is highly obscure to the student. We shall state it in a form, such that it will apply to the analogous hyperbolic case. For brevity let n denote the square root of the difference of a^2 and b; in the hyperbolic case n is less than a. Equation (4) may then be written

$$q = e^{-at} \left(c_1 \, e^{int} + c_2 \, e^{-int} \right).$$

The arbitrary constants c_1 and c_2 are circular complex quantities; they are not perfectly arbitrary, but are connected in such a way that they involve only two independent quantities. Their magnitudes are equal and their angles supplementary. Hence we can write:

$$c_1 = c \, (\cos \varphi + i \sin \varphi),$$
$$c_2 = c \, (- \cos \varphi + i \sin \varphi);$$

then:

$$q = 2 \, c \, e^{-at} \left(\cos \varphi \, \frac{e^{i\,nt} - e^{-i\,nt}}{2} + i \sin \varphi \, \frac{e^{i\,nt} + e^{-i\,nt}}{2} \right)$$
$$= i \, 2 \, c \, e^{-at} \left(\cos \varphi \sin nt + \sin \varphi \cos nt \right)$$
$$= i \, 2 \, c \, e^{-at} \sin (nt + \varphi).$$

The i is dropped, $2c$ is written A, and thus equation (6) is obtained.

The assumptions usually made in reducing are

$$c_2 = c\,(\cos\varphi + i\sin\varphi) \text{ and } c_2 = c\,(\cos\varphi - i\sin\varphi)$$

which is equivalent to making the angles conjugate. The solution then is

$$q = 2\,c\,e^{-at}\cos\,(nt + \varphi)$$

which is the horizontal instead of the vertical projection. The analogous investigation shows that the former is the correct assumption for the initial conditions of the discharge.

In the case of the hyperbolic roots

$$q = e^{-at}\left(c_1\,e^{\sqrt{-1}\,i\,nt} + c_2\,e^{-\sqrt{-1}\,i\,nt}\right).$$

Let

$$c_1 = c\,(\cosh\varphi + \sqrt{-1}\,i\sinh\varphi),$$

and

$$c_2 = c\,(-\cosh\varphi + \sqrt{-1}\,i\sinh\varphi);$$

then

$$q = \sqrt{-1}\,i\,c\,e^{-at}\left(\cosh\varphi\,\frac{e^{\sqrt{-1}\,i\,nt} - e^{-\sqrt{-1}\,i\,nt}}{2}\right.$$
$$\left.+\sinh\varphi\,\frac{e^{\sqrt{-1}\,i\,nt} + e^{-\sqrt{-1}\,i\,nt}}{2}\right)$$
$$= \sqrt{-1}\,i\,2\,c\,e^{-at}\sinh\,(nt + \varphi),$$

and by dropping $\sqrt{-1}\,i$ and writing A for $2\,c$,

$$q = A\,e^{-at}\sinh\,(nt + \varphi).$$

Were conjugate hyperbolic angles taken for the arbitrary constants, the horizontal projection would be obtained, involving $\cosh\,(nt + \varphi)$ in which case the initial current could not be zero. Either projection satisfies the differential equation, but it is only the former which satisfies the initial condition that there is no current at the beginning.

The meaning of these solutions is illustrated by Figs. 3 and 4.

Fig. 3 represents the circular case. O P multiplied by c represents c_1, and O P^1 multiplied by c represents c_2; O Q multiplied by $c\,e^{-at}$ represents the first circular solution and O Q^1 multiplied by the same quantity represents the supplementary circular solution. The multiples of O Q and O Q^1 are compounded, their resultant being $2\,c\,e^{-at}$ of O M which represents sin $(nt + \varphi)$.

In the hyperbolic case (Fig. 4), O P multiplied by c represents c_1, and O P^1 multiplied by c represents c_2; O Q multiplied by $c\,e^{-at}$ represents the first hyperbolic solution, and O Q^1 multiplied by the same ratio represents the supplementary hyperbolic solution. The multiples of O Q and O Q^1 are compounded, their resultant being $2\,c\,e^{-at}$ of O M, which represents the sine of the hyperbolic angle $n\,t + \varphi$.

By differentiation we deduce the solution for the current; let it be denoted by I. As $I = \dfrac{d\,q}{d\,t}$

$$I = -A\,e^{-at}\,[a \sinh (nt + \varphi) - n \cosh (nt + \varphi)]$$

$$= -A\,\sqrt{a^2 - n^2}\,e^{-at}\left[\frac{a}{\sqrt{a^2 - n^2}} \sinh (nt + \varphi) - \frac{n}{\sqrt{a^2 - n^2}} \cosh (nt + \varphi)\right]$$

$$= -A\,\sqrt{a^2 - n^2}\,e^{-at} \sinh \left(nt + \varphi - \tanh^{-1}\frac{n}{a}\right).$$

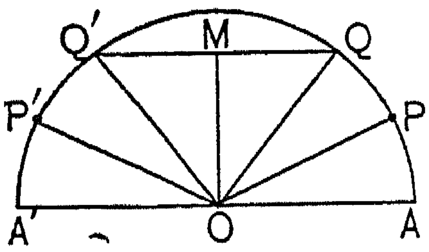

FIG. 3.

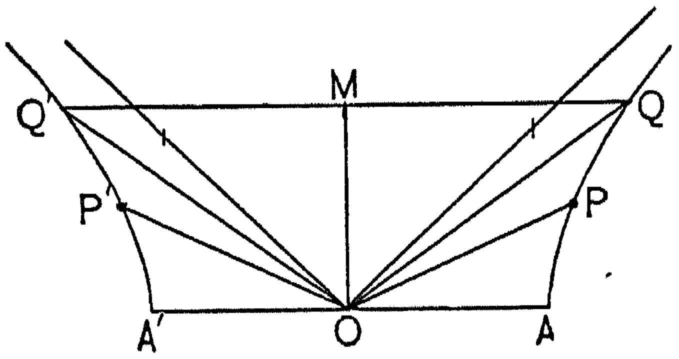

FIG. 4.

Thus the charge is in advance of the current by the hyperbolic angle whose tangent is $\frac{n}{a}$, which is the hyperbolic angle at which both q and I have their maximum value. The same proposition applies, *mutatis mutandis*, to the oscillating discharge.

Writers on this subject call $\frac{1}{a}$ the time constant for an exponential discharge, and $\dfrac{1}{-a + \sqrt{a^2 - b}}$ and $\dfrac{1}{-a - \sqrt{a^2 - b}}$ the time constants for the non-oscillating discharge. But from the above presentation of the subject it is evident that $\sqrt{a^2 - b}$ is the analogue of $\sqrt{b - a^2}$ in the circular case. There it means the angular velocity of the auxiliary circular motion; so here it means the angular velocity of the auxiliary equilateral-hyperbolic motion. In the oscillating case $\frac{2\pi}{\sqrt{b - a^2}}$ gives the period; in the non-oscillating case $\frac{2\pi}{\sqrt{a^2 - b}}$ gives the hyperbolic period. By the hyperbolic period is meant the time occupied by the radius-vector of the equilateral hyperbola of unit semi-axis to sweep out twice the area of the circle of unit radius. This definition of *period* applies to the circular case also.

The function $A \sin (nt + \varphi)$ represents the vertical projection of a uniform circular motion of amplitude A, angular velocity n, and epoch φ. Similarly the function $A\, e^{-at} \sin (nt + \varphi)$ represents (Fig. 5) the vertical projection of the circular spiral motion of the point P having angular velocity n, epoch φ and logarithmically decreasing amplitude $A\, e^{-at}$. In the same manner the function $A\, e^{-at} \sinh (nt + \varphi)$ represents (Fig. 6,) the vertical projection of the hyperbolic spiral motion of the point P having hyperbolic angular velocity n, epoch the hyperbolic angle φ, and amplitude $A\, e^{-at}$. It will be observed that this spiral is convergent, for n is less than a.

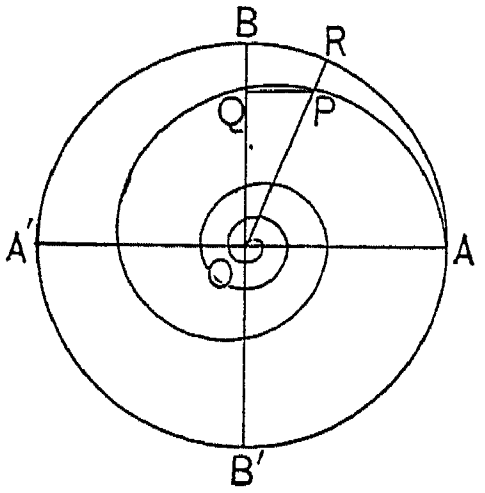

FIG. 5.

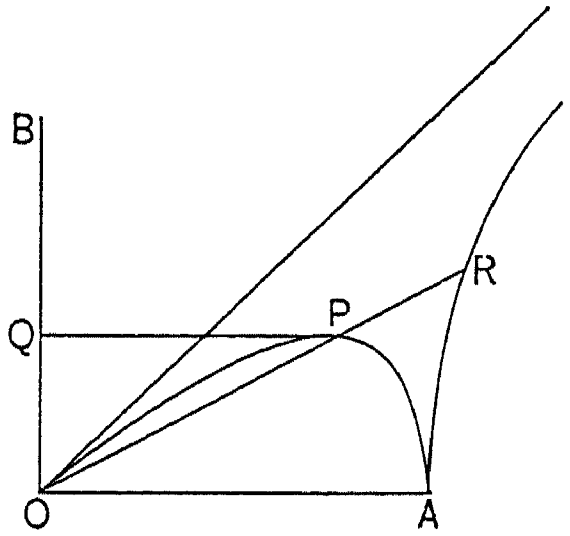

FIG. 6.

By putting in the conditions that $I = 0$ and $q = Q$ when $t = 0$, we obtain

$$\varphi = \tanh^{-1} \frac{n}{a}, \text{ and } A = Q\, \frac{\sqrt{a^2 - n^2}}{n}$$

consequently

$$q = Q\, \frac{\sqrt{a^2 - n^2}}{n}\, e^{-at} \sinh \left(nt + \tanh^{-1} \frac{n}{a}\right)$$

and

$$I = -\, Q\, \frac{a^2 - n^2}{n}\, e^{-at} \sinh nt.$$

These curves have a maximum value when the angle is $\tanh^{-1}\frac{n}{a}$; hence when $t = o$ and $t = \frac{1}{n}\tanh^{-1}\frac{n}{a}$ respectively. They have a point of contrary flexure, when the angle is $2\tanh^{-1}\frac{n}{a}$; hence when $t = \frac{1}{n}\tanh^{-1}\frac{n}{a}$ and $t = \frac{n}{2}\tanh^{-1}\frac{n}{a}$ respectively. The properties of either curve are given by the general equation

$$\frac{d^m q}{dt^m} = (-1)^m Q \frac{\sqrt{(a^2 - n^2)}^{m+1}}{n} e^{-at} \sinh\left[nt - (m-1)\tanh^{-1}\frac{n}{a}\right]$$

corresponding to

$$\frac{d^m q}{dt^m} = (-1)^m Q \frac{\sqrt{(a^2 + n^2)}^{m+1}}{n} e^{-at} \sin\left[nt - (m-1)\tan^{-1}\frac{n}{a}\right]$$

in the oscillating case.

The nature of the curves for the charge and the current in the non-oscillating case has not been plain to some electricians of high authority. In the first volume of his work, "Alternating Current Transformer," page 379, Professor Fleming represents the current graphically by an exponential curve, which is far from representing the current correctly. In the first volume of his "Lecons sur l'Electricité," page 256, Professor Gerard represents the charge by an exponential curve which has no maximum at the beginning; and the same representation is given by Professors Jackson in appendix C of their "Alternating Currents." The curves are correctly represented graphically by Doctors Bedell and Crehore in their "Alternating Currents," and by Professor Webster in his "Theory of Electricity and Magnetism."

We deduce the solution for the transition case by means of the principle that in form it must agree with what is common to the two general solutions. Now for the hyperbolic case

$$q = A\,e^{-at}\left[nt + \varphi + \frac{(nt+\varphi)^3}{3!} + \right],$$

and for the circular case

$$q = A\,e^{-at}\left[nt + \varphi - \frac{(nt+\varphi)^3}{3!} + \right];$$

hence for the transition case

$$q = A\, e^{-at}\, (\varphi + n\,t).$$

As $A\ \varphi$ is represented by a length, and $A\ n$ by a linear velocity, let them be denoted by the constants $2\ c$ and $2\ v$. Then $q = 2\ e^{-at}\ (c + v\,t)$.

In the case of the horizontal projections the only common part is the first term of the series, namely 1; hence b denoting an arbitrary length, we have $2\ e^{-at}\ b$ for that projection. Hence the primary form of the solution of the differential equation in the transition case is

$$q = e^{-at} \{ [b + i\,(c + v\,t)\,] + [-b + i\,(c + v\,t)\,] \}.$$

This is represented in Fig. 7, which is the transition between Figs. 3 and 4. O P represents $b + i\,c$, and O P¹ represents $-b + i\,c$; O Q represents $b + i\ (c + v\,t)$ and O Q¹ represents $-b + i\ (c + vt)$; O M represents half of the resultant of O Q and O Q¹.

By putting in the conditions that $I = 0$ and $q = Q$ when $t = 0$, we obtain

$$q = Q\ e^{-at}\ (a\,t + 1)$$

$$\text{and } I = -\ Q\ e^{-at}\ a^2\,t.$$

The general differential co-efficient is

$$\frac{d^{\mathrm{m}}\,q}{d\,t^{\mathrm{m}}} = (-1)^{\mathrm{m}}\ Q\,e^{-at}\ a^{\mathrm{m}} \left[a\,t - (m - 1) \right].$$

Hence q is a maximum when $t = o$, and has a point of contrary flexure when $t = \frac{1}{a}$; and I has a maximum when $t = \frac{1}{a}$ and a point of contrary flexure when $t = \frac{2}{a}$. Thus we see that 1 takes the place of $\tan^{-1} \frac{n}{a}$ or $\tanh^{-1} \frac{n}{a}$, and that a takes the place of n.

Fig. 8 is the transition between Figs. 5 and 6. The point R describes a uniform motion along the straight line; O P is O R diminished at a uniform geometrical rate, O Q is the vertical projection of O P. The path of P is perpendicular to O A at the point O, whereas in the hyperbolic case it makes an angle of 45°.

If attention is restricted to real roots, it is difficult to see why the transition solution is not of the form $q = A\ e^{-at}$, nor is the matter made very clear in treatises on Differential Equations.

The preceding investigation throws new light on the theory of the quadratic equation. The current theory may be stated as follows: A quadratic equation has either two real roots, or two imaginary roots, the separating case being when the roots are equal. According to the results of the preceding investigation, the theory should be stated as follows: So far as real roots are concerned, a quadratic equation has either two such roots, or else none, the separating case being where they are equal. The two general cases are the real and the impossible. As regards complex roots, a quadratic equation has either two conjugate hyperbolic roots, or else, two conjugate circular roots, the separating case being where they are straight-line. Consider the quadratic equation $x^2 + 2\,ax + b = 0$. If a^2 is greater than b, the roots are hyperbolic, and

$$x_1 = -a + \sqrt{-1}\, i \sqrt{a^2 - b}$$

$$x_2 = -a - \sqrt{-1}\, i \sqrt{a^2 - b}$$

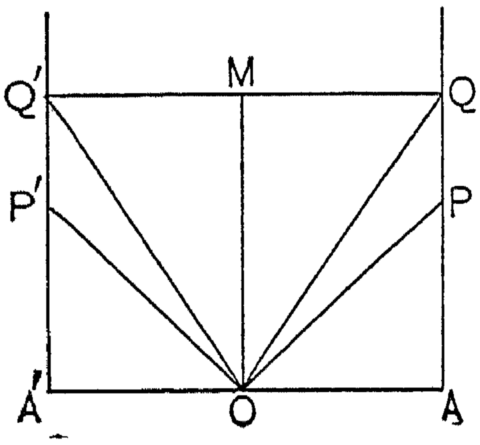

FIG. 7.

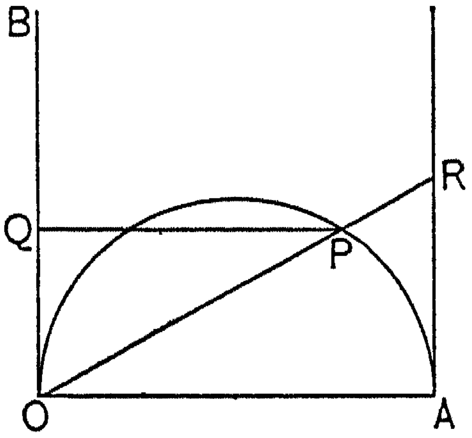

FIG. 8.

If we substitute either root in the equation, we shall find, just as in the case of the circular roots, that the terms which do not involve i cancel one another, and likewise the terms which do involve i. The equation is doubly satisfied by the independent vanishing of the two parts.

The preceding investigation has an important bearing on the theory of the complex quantity, a theory which lies at the foundation of algebraic analysis. The eminent mathematician Cayley maintained that the complex quantity $a + ib$ is the most general magnitude considered by algebra, and that were it fully investigated the science would become *totus teres atque rotundus*. The current doctrine among mathematicians is thus stated in a recent able work on alternating currents, where from the nature of the subject the circular complex quantity is a fundamental idea:

"Within the range of algebra no further extension of the system of numbers is necessary or possible, and the most general number is $a + ib$, where a and b can be integers or fractions, positive or negative, rational or irrational." [1]Let the question be limited to the algebra of the plane although that is in truth an arbitrary restriction, for spherical trigonometrical analysis is as much algebra as is plane trigonometrical analysis. The preceding investigation shows that the ordinary complex quantity is only one-half of the whole subject of plane algebra; for parallel with the circular complex quantity we have a hyperbolic complex quantity, and for every theorem about the former there is an analogous theorem about the latter. If the one is within the domain of algebra, so is the other. Here we have another instance of the danger involved in predicating *impossible.*

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[1] Steinmetz, "Alternating Current Phenomena," p. 405.

DISCUSSION AT ELIOT, ME., JULY 27, 1897.

MR. CHAS. P. STEINMETZ:—I have been very much interested in this paper of Dr. Macfarlane's, since it offers a common method of calculation for the two different classes of phenomena which can take place, if a condenser discharges through a circuit of resistance and inductance. Such a condenser discharge can either be an oscillating current, that is, a current similar to an alternating current, but gradually decreasing in amplitude, or it may be a steady discharge, that is a gradual dying out without reversal. The former is the case if the resistance of the circuit is below, the latter if it is beyond a certain critical value.

The usual method of investigation of these phenomena leads to two different functions, an exponential function for the steady discharge which becomes imaginary if the resistance is below the critical value, and a trigonometric function for the oscillating discharge which becomes imaginary if the resistance is above the critical value.

Both these two forms of discharge are apparently entirely different from each other, nevertheless in reality they are of the same nature and gradually change into each other as you will best see by considering a mechanical analogon, as a pendulum in motion. A pendulum, when set in motion in air, will make a lesser or larger number of oscillations with gradually decreasing amplitude, until it comes to a standstill. The rapidity of decrease of oscillations depends upon the resistance of the medium in which it moves, thus for instance in a more resisting medium as in water, the amplitude of oscillation of the pendulum will decrease much faster than in air and it will come to rest very shortly. In a still more viscous medium the oscillations will die out still more rapidly and only very few oscillations take place and ultimately only a half oscillation, that is, the pendulum will be brought to rest by the resistance of the medium without ever passing over the position of equilibrium. The latter case is analogous to the steady discharge.

It is very gratifying to see in the paper these two sides of the same phenomenon of condenser discharge, represented by the same symbolism.

There is, however, one sentence in the end of the paper in reference to a statement which I made once regarding the position of the complex imaginary quantity in algebra. I am sorry to say that I cannot agree with Dr. Macfarlane on this point, but have to maintain my former position.

All the eminent mathematicians of modern times as far as they have taken position at all, have considered the complex imaginary quantity as the most general algebraic quantity, and that there is no further extension of algebra possible outside of the complex imaginary quantity. It is obvious that these mathematicians cannot possibly have been mistaken.

In opposition hereto, Dr. Macfarlane takes the stand that there are other complex imaginary quantities possible outside of the complex imaginary one, and even offers here in the paper a complex imaginary or hyperbolic quantity outside of the complex quantity of pure mathematics. It is evident that there must be a mistake somewhere, and we can discover the mistake by looking on page 165 of Dr. Macfarlane's paper, where he introduced this hyperbolic complex imaginary quantity. He says there in the second line, "If we inquire into the geometrical meaning of the $\sqrt{-1}$ here appearing, we shall find that it means a quadrant of turning round the axis perpendicular to the plane of reference," then he introduces the hyperbolic quantity. This shows the source of the mistake. The quantity introduced here by Dr. Macfarlane is a vector symbolism, that is the symbolic representation of a plane vector, or in other words, of a geometrical relation, similar as for instance the system of quaternions is a space vector symbolism. A vector symbolism is not yet an algebraic quantity, for instance the quarternions are not algebraic quantities.

Undoubtedly the number of possible vector symbolisms is unlimited, the number of algebraic quantities is however limited.

We have thus to see what is the meaning of an algebraic quantity.

An algebraic quantity is a quantity with which we can operate by the common rules of algebra, that is, multiply, divide, solve equations, etc.

There is one fundamental principle underlying all algebraic operation, that is the principle that if a product is zero one of the factors must be zero.

Even the simplest calculations are based on this principle. Take for instance the case that you have measured a resistance r and find,

$$5\,r = 20$$

everybody will say herefrom,

$$r = 4.$$

Explicitly the operations were,

$$\begin{aligned} 5\,r &= 20 \\ 5\,r - 20 &= 0 \\ 5\,(r - 4) &= 0 \\ r - 4 &= 0 \\ r &= 4 \end{aligned}$$

As you see in deriving this result $r = 4$ from $5\,r = 20$, a result which everybody would take for granted immediately, we have made use of the fundamental principle of algebra by cancelling with 5, that is assuming that if the product $5\,(r - 4) = 0$ and the one factor 5 is not zero, the other factor $r - 4$ must be zero. Thus if this principle does not hold, the calculation would be erroneous, or in other words, every possibility of calculation would cease, and it is erroneous for quantities which are not algebraic, as for instance for the hyperbolic vector quantity introduced by Dr. Macfarlane.

Let us see now how the complex imaginary quantity stands with regard to this fundamental principle of algebraic quantities.

Let $a + j\,b$ be a complex imaginary quantity and $x + j\,y$ another complex imaginary quantity. Let their product be zero, that is,

$$(a + j\,b)\,(x + j\,y) = 0$$

If now $a + j\,b$ is a quantity differing from zero, the above mentioned fundamental principle of algebra requires that we can cancel the equation with $a + j\,b$ and thus get,

$$x + j\,y = 0$$

that is in other words, if $(a + j\,b)\,(x + j\,y) = 0$ and $a + j\,b$ differs from zero, $x + j\,y$ must be zero, if the complex quantity is an algebraic quantity.

From $(a + j\,b)\,(x + j\,y) = 0$ it follows:

$$(a\,x + j^2\,b\,y) + j\,(a\,y + b\,x) = 0$$

or since $j^2 = -1$ by definition of the imaginary unit, it is

$$(a\,x - b\,y) + j\,(a\,y + b\,x) = 0$$

since, however, j is a different kind of unit, either of the two terms of the last equation must be zero, that is,

$$a\,x - b\,y = 0$$
$$a\,y + b\,x = 0$$

Since a and b differ from zero, we can eliminate a and b from these two symmetrical equations and get the result,

$$x^2 + y^2 = 0$$

This condition can be fulfilled only by

$$x = 0$$
$$y = 0$$

that means $x + j\,y = 0$.

Thence from the equation,

$$(a + j\,b)\,(x + j\,y) = 0$$

it follows,

$$x + j\,y = 0$$

that is the complex imaginary quantity is an algebraic quantity and can be treated as such.

Take, however, the hyperbolic complex quantity introduced by Dr. Macfarlane.

The hyperbolic imaginary unit of his is, $\sqrt{-1}\,\beta^{\frac{\pi}{2}}$ or $i\,\sqrt{-1}$. For brevity, we may denote: $i\,\sqrt{-1} = k$. It is defined by,

$$k^2 = +1$$

assuming again the product of two such complex quantities equal zero:

$$(a + k\,b)\,(x + k\,y) = 0$$

it follows

$$(a\,x + k^2\,b\,y) + k\,(a\,y + b\,x) = 0$$

or since $k^2 = +1$ and the two terms of the last equation are of different nature, it follows,

$$a\,x + b\,y = 0$$
$$a\,y + b\,x = 0$$

or, eliminating a and b, we get,

$$x^2 - y^2 = 0$$

that is,

$$x = \pm\,y$$

This means, if $x = \pm\,y$, the product $(a + k\,b)\,(x + k\,y)$ can be zero without either factor being zero.

Since x and y differ from zero it follows analogously, as condition of zero value of the above given product, that,

$$a = \mp\,b$$

that is, if in two hyperbolic complex imaginary quantities the coefficient of the real term equals the coefficient of the imaginary term, but the signs of the imaginary components are opposite, the product of these two hyperbolic complex quantities is zero without either factor being zero.

$$(a \pm k\,a)\,(x \mp k\,x) = 0$$

Furthermore it follows that the hyperbolic complex imaginary quantity of this paper is not an algebraic quantity, and that equations in such quantities cannot be handled by the laws of algebra, for instance, cannot be cancelled by a constant factor without being liable to see an equality changed into an inequality. That means the hyperbolic imaginary quantity, while a vector symbolism, is not an algebraic quantity, and my statement that the complex imaginary quantity is the only and most complete algebraic quantity still holds.

Dr. A. E. Kennelly:—I am sorry that Dr. Macfarlane is not with us, because we might expect an animated discussion on the points Mr. Steinmetz has raised. There are several matters of great interest in this paper. I will only venture to call attention to two of them.

We all know that if a plane cuts a right cone at right angles to its axis, the curve of intersection is a circle. If the cutting plane is tilted, the circle becomes an ellipse; until, when the plane is parallel to one side of the cone the curve becomes a parabola; and, finally when the plane is tilted beyond this position the curve is a hyperbola.

The results pointed out by the author may be expressed as follows: When a perfect condenser discharges through a perfectly conducting circuit, *i. e.*, a resistanceless circuit, containing inductance, the discharge is oscillatory without damping, and may be represented by the motion of a point in an ellipse with equiangular velocity around the centre, the angle being measured elliptically; or, by the motion of a point in a circle with equiangular velocity, as a particular case of the ellipse.

When the discharging circuit is not perfectly conducting, but offers a resistance, such that its magnetic time-constant is greater than one-fourth of the static time-constant, the discharge, no longer undamped, may be represented by equiangular velocity in an ellipse—with the circle as a particular case—accompanied by a logarithmic shrinking of the radius vector. The trace of the point's motion is therefore a logarithmic spiral, or an orthogonal projection of the same on an inclined plane, *i. e.*, a logarithmic elliptical spiral.

When the discharging circuit has so much resistance that the magnetic time-constant is greater than one-fourth of the static time-constant, the cutting plane of the cone must be tilted from the elliptic curve to the hyperbolic curve. The discharge of the condenser may now be represented by equiangular velocity in the hyperbola, a rectangular hyperbola as a particular case, accompanied by logarithmic shrinking of the radius vector. The trace of the point's motion is therefore a logarithmic hyperbolic spiral.

When the discharging circuit has critical resistance, so that the magnetic time constant l/r is one-fourth of the static time constant or $c\,r/4$, the cutting plane must occupy the intermediate position, and the curve becomes a parabola. The discharge of the condenser may now be represented by equiangular velocity in the parabola, accompanied by logarithmic shrinking of the radius vector. The trace of the point's motion is therefore a logarithmic parabolic spiral.

I do not mean that the above statements are all in the paper before us, although some of them are there. I mean that these are conclusions to which the very interesting treatment in the paper appears to lead.

The second point is of less interest to us as electricians, it is at present almost wholly of mathematical interest. The square root of minus unity was originally called imaginary, because it was regarded as a logical reduction to an impossible or unusual result. Later it became readily interpreted geometrically as the operator which rotates a line counter-clockwise in a plane through a right angle. No other interpretation has hitherto been given to this symbol so far as I know. Dr. Macfarlane now points out that it is also capable of a new meaning in which it is not a versor but a scalar.

MR. STEINMETZ:—I may add that whatever criticisms I have made does not apply to the particular application of hyperbolic imaginary quantities made by Dr. Macfarlane, since in his paper these complex quantities are never used as products, as for instance, common complex imaginary quantities are used when deriving E. M. F. as product of current, impedance, etc. It is only in this latter case where it becomes essential that the complex quantity is an algebraic quantity.

DR. F. A. C. PERRINE:—There is just one point—in speaking of complex quantities, which are really not the subject of the paper, but nevertheless have been brought up in this discussion—in respect to which I think there is an error that has been commonly committed and has interfered with the general understanding of the complex quantity, and that is the error of considering the introduction of the complex quantity solely, as Mr. Kennelly says, for the geometrical interpretation of a particular mathematical symbol, and that our interpretation of the complex quantity is that if we plot along one axis the value J, and on the other axis the value of the real quantity—we will call it A—than any vector may be represented by a sum which we will call $A + B J$. Now additions or subtractions may be performed entirely geometrically. Let us attempt to obtain a multiplication. Take another vector which we will call $C + D J$, and commonly we refer this to a unit vector in order to obtain multiplication, take this point as the unit vector, then the multiplication of these two quantities is performed by drawing on the first vector a triangle entirely similar to the triangle drawn by joining the end of the unit vector and the second vector. This will give us a third vector which, in the geometrical interpretation, has been sometimes called the product of these two vectors. Now as an actual fact, that is not the product which we can use in our analytical working, for the real product of these two vectors is the product of their scalar values times the cosine of the angle between them, which is an entirely different product from this geometrical form of product. This is an error I have never seen pointed out, though I have noticed more than one writer, shortly after the World's Fair, who began to explain the system, and after reaching geometrical multiplication was compelled to stop, because the saying that this vector representation of the complex quantity is a geometrical method of interpreting the square root of minus one, fails as soon as we accept the geometrical method of multiplication which is the only method of multiplication of the complex vectors which has been at all described in the chapters in the algebras on the complex quantities, and it leads to entirely wrong results, and it shows at once that the true method of dealing with the complex quantities is an algebraic method and not at all a geometric method.

MR. STEINMETZ:—I agree with the last speaker that in multiplying complex imaginary quantities we have to deal algebraically, since in multiplying two complex imaginary quantities geometrically, the product of the two quantities may have no meaning.

In the geometrical multiplication the product of two complex quantities as vectors is a vector again. Wherever the product of the two quantities represented by the complex numbers is not a vector quantity, it is obviously not feasible to represent it in the diagram by a vector, and thus the geometrical multiplication becomes meaningless. This is for instance the case when multiplying current and E. M. F. to derive the power, since power is of double frequency and thus cannot be represented in the polar vector diagram of single frequency.

DR. PERRINE:—That is perfectly true; but at the same time it is not as much a foregone conclusion as you might think; because I was taught to multiply these complex quantities in that way by a man who had learned it from no less a man than Weyerstrass in Germany, and this was given to me as the sum of knowledge in regard to complex quantities, and I think that a great many learners have been confused by exactly that error in the geometrical interpretation of complex quantities.

MR. STEINMETZ:—The geometrical multiplication of complex quantities is obviously just as correct as the algebraical multiplication, wherever the product can be represented geometrically, that is wherever the product is a vector, as for instance when multiplying current with impedance or E. M. F. with admittance. Only where the product of the two vectors is not a vector, as when multiplying current and E. M. F., the geometrical multiplication which gives a vector as product, becomes meaningless.

DR. LOUIS BELL:—It seems to me that this discussion gives a very beautiful example of how not to use certain mathematical symbols. I think we owe to Mr. Steinmetz a great deal for his clever manipulation of the imaginary quantity in the solution of physical problems, but I do not know that anything has been brought out more clearly in this discussion, than the necessity of tying yourself up to your physical conceptions. Whenever you let yourself loose and deal with imaginary quantities which have not a close and precise physical meaning, you are apt to get into trouble. Just so long as you tie yourself up, keep out your sheet anchor, look sharply as to the character of the quantities with which you are dealing, you will derive very valuable results. As soon as you cease remembering that these imaginary quantities are means to an end, that they form a vastly convenient and very precise method of dealing with certain physical things—as soon as you forget that, and start with a free hand to swing your complex quantities for the purpose of seeing what transcendental results you can get, then you are almost ready to get into difficulty. Mr. Steinmetz has given us some beautiful examples of the way in which it should be used, and Dr. Perrine has certainly given one or two examples of the way in which it should not be used. That fact runs all through our physical mathematics; that as soon as you get out of sight of physical interpretations and start out with a free sheet your cruise may bring you to some place which you desire to reach; it may land you in a place from which nothing but an all-wise providence can extricate you.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Fourteenth General Meeting.

Greenacre-on-the-Piscataqua,
Eliot, Me., July 26, 27 and 28, 1897.

The opening session of the Fourteenth General Meeting of the Institute was called to order by President Crocker at the "Eirenion," Greenacre, on Monday, July 26th at 2 p. m.

The Secretary announced that the papers to be presented had already been printed in the May, June and July issues of the Transactions with the exception of the last three appearing on the programme.

The following Associate Members were elected and transferred at the meeting of Council, June 23, 1897.

Name.	Address.	Endorsed by.
Atkins, Harold B.	Engineer, A. K. Warren & Co., 451 Greenwich St., N. Y. City, residence, Roselle, N. J.	Townsend Wolcott C. O. Mailloux. A. K. Warren.
Copeland, Clement A.	Manager of Electric Lighting Station and Electrician, Copper Queen Consolidated Mining Co., Bisbee, Arizona.	Edw. L. Nichols. Fred'k. Bedell. Harris J. Ryan.
Damon, Geo. B.	Consulting Engineer, F. P. Sheldon & Co., 612 Exchange Building, Boston, residence Lowell, Mass.	C. F. Bancroft. Chas. A. Stone. Russell Robb.
Edmands, I. R.	Construction Engineer, General Electric Co., 315 Buffalo Ave., Niagara Falls, N. Y.	Chas. P. Steinmetz Ernst J. Berg. Paul M. Lincoln.
Ellard, John W.	Treasurer, Edison Electric Illuminating Co., 15 South Street, Baltimore, Md.	J. F. Morrison. Chas. F. Wallace. H. K. McCay.
Scott, Wm. M.	Electrical Engineer. The Cutter Electrical and Mfg. Co., 1112 Samson St., Philadelphia, Pa.; residence, 108 West Johnson St., Germantown, Pa.	Clayton W. Pike. W. E. Harrington. H. F. Albright.

WILLIAMS, ARTHUR	General Inspector, The Edison Electric Illuminating Co., of New York; residence, 155 Linden Boulevard, Brooklyn, N. Y.	J. W. Lieb, Jr. A. E. Kennelly. Townsend Wolcott Douglas Burnett.

Total 7.

TRANSFERRED FROM ASSOCIATE TO FULL MEMBERSHIP.

Approved by Board of Examiners June 21, 1897.

HAMMER, E. W.	New York City.
LEWIS, MINFORD,	Philadelphia, Pa.

Total 2.

Mr. Charles P. Steinmetz then read the following paper on "The Alternating Current Induction Motor."

A paper presented at the 14th General Meeting of the American Institute of Electrical Engineers, Eliot, Me., July 26th, 1897. President Crocker in the Chair.

THE ALTERNATING CURRENT INDUCTION MOTOR.

BY CHARLES PROTEUS STEINMETZ.

POLYPHASE INDUCTION MOTOR.

§ 1. *Load Curves.*—In its general behaviour the alternating current induction motor is analogous to the continuous current shunt motor. Like the shunt motor it operates at approximately constant magnetic density. It will run at fairly constant speed, slowing down gradually with increasing load. The main difference, however, is that in the induction motor the current is not passed into the armature by a system of brushes, as in the continuous current motor, but induced in the armature by the alternating field, and in consequence thereof, the primary circuit of the induction motor fulfils the double function of an exciting circuit corresponding to the field circuit of the continuous current shunt motor, and an inducing circuit producing the current in the armature by electro-magnetic induction.

In its electro-magnetic features, however, the induction motor is essentially a transformer. That is, it consists of a magnetic circuit interlinked with two electric circuits, the primary or inducing, and the secondary or induced circuit. The difference between transformer and induction motor is that in the former the secondary is fixed regarding the primary, and the electrical energy induced in the secondary is made use of, while in the latter the secondary is movable regarding the primary and the mechanical force acting between primary and secondary is used.

The secondary or armature of the motor consists of two or more circuits displaced in phase from each other so as to offer a closed secondary to the primary circuits, irrespective of the relative motion. The primary consists of one or several circuits.

In consequence of the relative motion of the primary and secondary, the magnetic circuit of the induction motor must be arranged so that the secondary while revolving does not leave the magnetic field of force. That means the magnetic field of force must be of constant intensity in all directions, or in other words the component of magnetic flux in any direction in space be of the same or approximately the same intensity but differing in phase. Such a magnetic field can either be considered as superposition of two magnetic fields of equal intensity in quadrature in time and space, or it can be represented theoretically by a revolving magnetic flux of constant intensity, or simply treated as alternating magnetic flux of the same intensity in every direction.

In the polyphase motor this magnetic field is produced by a number of electric circuits displaced from each other in position in space, and excited by currents having the same displacement in phase as the exciting coils have in space.

In the monocyclic motor the one of the two superimposed quadrature fields is excited by the primary energy circuit, the other by the magnetizing or teaser circuit.

In the single phase motor the one of the two superimposed magnetic quadrature fields is excited by the primary electric circuit, the other by the induced secondary or armature currents carried into quadrature position by the rotation of the secondary.

In either case, at or near synchronism the magnetic fields are identical.

The transformer feature being predominant, in theoretical investigations of induction motors it is generally preferable to start therefrom.

The characteristics of the transformer are independent of the ratio of transformation, other things being equal. That is, doubling the number of turns for instance, and at the same time reducing their cross-section to one-half, leaves the efficiency, regulation, etc., of the transformer unchanged. In the same way in the induction motor it is unessential what the ratio of primary and secondary is, or in other words the secondary circuit can be wound for any suitable number of turns, provided the same total copper cross-section is used. In consequence hereof the secondary circuit is mostly wound with one or two bars per slot, to get maximum amount of copper, that is minimum resistance of secondary.

The general characteristics of the induction motor being independent of the ratio of turns, it is for theoretical considerations simpler to assume the secondary motor circuit reduced to the same number of turns as the primary, or the ratio of transformation 1, by multiplying all secondary currents and dividing all secondary electromotive forces with the ratio of turns, multiplying all secondary impedances and dividing all secondary admittances by the square of the ratio of the turns, etc.

Thus in the following under secondary current, E. M. F. impedance, etc., shall always be understood their values reduced to the primary, or corresponding to a ratio of turns 1 to 1, although in practice a ratio 1 to 1 will hardly ever be used, as not fulfilling the condition of uniform magnetic reluctance desirable in the starting of the induction motor.

Let in the polyphase induction motor

$Y_0 = g + j\,b$ = primary admittance, or admittance of the primary circuit at open secondary circuit.

$Z_0 = r_0 - j\,x_0$ = primary impedance.

$Z_1 = r_1 - j\,x_1$ = secondary impedance reduced to the primary by the ratio of turns.[1]

All these quantities refer to one primary circuit and one corresponding secondary circuit. Thus in a three-phase induction motor the total power, etc., is three times that of one circuit, in the quarter-phase motor with three-phase armature the impedance of $1\frac{1}{2}$ of the three secondary circuits is to be considered as corresponding to each of the two primary circuits, etc.

Let

e = primary counter electromotive force, or electromotive force induced in the primary circuit by the flux interlinked with primary and secondary (mutual induction).

s = slip, with the primary frequency as unit, that is, $s = O$ denoting synchronous rotation, $s = 1$ standstill of the motor.

It is then:

$1 - s$ = speed of the motor secondary as fraction of synchronous speed.

$s\,N$ = frequency of secondary currents, where

N = frequency impressed upon the primary

hence

$s\,e$ = E. M. F. induced in the secondary.

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[1] The self inductive reactance refers to that flux which surrounds one of the electric circuits only without being interlinked with the other circuits.

The actual impedance of the secondary circuit at the frequency $s\,N$ is

$$Z_1^s = r_1 - j\,s\,x_1$$

hence,

Secondary current:

$$I_1 = \frac{s\,e}{Z_1^s} = \frac{s\,e}{r_1 - j\,s\,x_1} = e\left(\frac{s\,r_1}{r_1^2 + s^2 x_1^2} + j\,\frac{s^2\,x_1^2}{r_1^2 + s^8\,x_1^2}\right) = e\,(a_1 + j\,a_2)$$

where:

$$a_1 = \frac{s\,r_1}{r_1^2 + s^2\,x_1^2} \qquad a_2 = \frac{s^2\,x_1^2}{r_1^2 + s^2\,x_1^2}.$$

Primary exciting current:

$$I_{00} = e\;Y_0 = e\,[g + j\,b]$$

hence,

Total primary current:

$$I_0 = e\,[\,(a_1 + g) + j\,(a_2 + b)\,] = e\,(b_1 + j\,b_2)$$

where:

$$b_1 = a_1 + g \qquad b_2 = a_2 + b.$$

The E. M. F. consumed in the primary circuit by the impedance Z_0 is $I_0\,Z_0$, the counter E. M. F. is e, hence:

Primary terminal voltage:

$$E_0 = e + I_0\,Z_0 = e\,[1 + (b_1 + j\,b_2)\,(r_0 - j\,s_0)] = e\,(c_1 + j\,c_2),$$

where:

$$c_1 = 1 + r_0\,b_1 + s_0\,b_2 \qquad c_2 = r_0\,b_2 - s_0\,b_1.$$

Eliminating complex quantities, it is:

$$E_0 = e\,\sqrt{c_1^2 + c_2^2};$$

hence,

Counter E. M. F. of motor:

$$e = \frac{E_0}{\sqrt{c_1^2 + c_2^2}},$$

where:

$$E_0 = \text{impressed E. M. F., numerical value.}$$

Substituting this value in the equations of I_0, I_{00}, I_0, etc., gives the complex expressions of currents and E. M. F.'s, and, eliminating the imaginary quantities, it is:

Secondary current:

$$I_1 = e\,\sqrt{a_1^2 + a_2^2}.$$

Exciting current:

$$I_{00} = e\,\sqrt{g^2 + b^2}.$$

Primary current:

$$I_0 = e\,\sqrt{b_1^2 + b_2^2}.$$

Denoting by:

$$[M\ N] = [(m_1 + j\ m_2)\ (n_1 + j\ n_2)] \text{ the product: } m_1\,n_1 + m_2\,n_2, \text{ it is:}$$

Torque:

$$T = [I_1\ e] = e^2\ a_1;$$

hence,

Power output:

$$P = (1 - s)\ T = e^2\ a_1\ (1 - s).$$

Primary input:

$$P_0 = [I_0\ E_0] = e^2\ (b_1\ e_1 + b_2\ c_2).$$

Voltamperes, or apparent input:

$$Q = I_0\ E_0.$$

The torque is by this equation given in watts at synchronism, that is $T =$ power which would be developed if the motor would run with this torque at synchronism. This makes us independent of the number of poles, frequency, speed, etc., and thus allows the direct comparison of motors.

The output P includes friction, windage, etc., thus the net mechanical output is P — friction, etc. Since however, friction, etc., depend upon the mechanical construction of the individual motor and its use, it cannot be included in a general formula. P is thus the mechanical output and T the torque developed at the armature conductors.

The efficiency is, $\frac{P}{P_0}$,

the power factor, $\frac{P_0}{Q}$,

the apparent efficiency, $\frac{P}{Q}$,

the torque efficiency, $\frac{T}{P_0}$,

the apparent torque efficiency, $\frac{T}{Q}$,

The meaning of these quantities is the following:

The "efficiency" or "power efficiency" is the ratio of the true mechanical output of the motor to the output which it would give at the same power input if there were no internal losses in the motor.

The "apparent efficiency" or "apparent power efficiency" is the ratio of the mechanical output of the motor to the output which it would give at the same volt-ampere input if there were neither internal losses nor phase displacement in the motor.

The "torque efficiency" is the ratio of the torque of the motor to the torque which it would give at the same power input if there were no internal losses in the motor.

The "apparent torque efficiency" is the ratio of the torque of the motor to the torque which it would give at the same volt-ampere input if there were neither internal losses nor phase displacement in the motor.

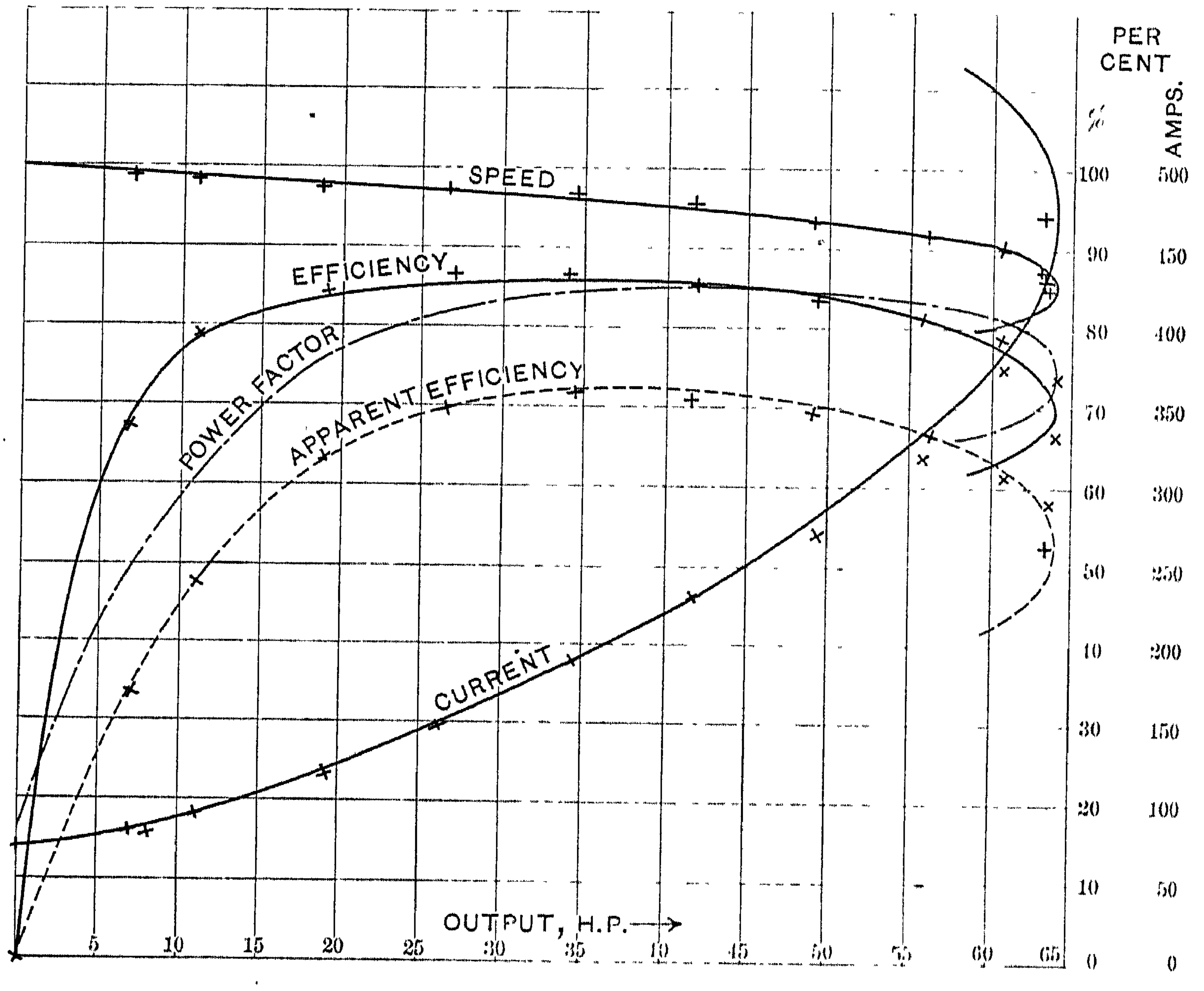


FIG. 1.

1–8–30–900–110, Form "A." 60 Cycles, 8 Poles, 110 Volts. Three Phase. Curves calculated with: $Y = .045 + .384j$; $Z_0 = .045 - .124j$; $Z_1 = .041 - .124j$. Friction: 510 Watts at Synchronism. Observed by Test: ×.

The torque efficiencies are of special interest in starting where the power efficiencies are necessarily zero, but it nevertheless is of importance to find how much torque per watt or per volt-ampere input is given by the motor. These terms are preferable to the terms "torque per watt" or "torque per volt-ampere" generally used in this case, since they are independent of the number of poles, frequency, etc., of the individual motor.

Thus from the quantities: primary admittance, primary impedance and secondary impedance, the induction motor can be calculated.

The predetermination of admittance and impedance belongs in the field of induction motor design and therefore falls outside of the scope of this paper.

As instance, in Figs. 1 and 2 are calculated the load and speed curves of a 60-cycle three-phase eight-polar motor, 110 volts impressed, of the constants.

$Y_0 = .045 + .384 j.$

$Z_0 = .045 - .124 j.$

$Z_1 = .041 - .124 j$ per circuit in delta connection.

510 volts are allowed as friction at synchronism.

The output and torque are three times the values derived directly from calculation since the motor contains three circuits, and the current shown in the diagrams is the current per line, or $\sqrt{3} \times$ the current derived from calculation.

In Fig. 1 are shown in drawn lines the speed, efficiency, and current input of the motor with the H. P. output as abscissae, in dotted lines the apparent efficiency, and in dash dotted lines the power factor.

In Fig. 2 are shown with the speed or the slips in per cent. of synchronism as abscissae, the torque as ordinates for the three-phase armature resistances:

$r_1 = .041$, or short-circuited armature.

$r_1 = .33.$

$r_1 = .76.$

This motor is the *I*-8-30-900-110, Form A, of General Electric Co's make, and the results of test of this motor are marked in Figs. 1 and 2 by crosses, showing the exceedingly close agreement between the calculated values and the results of test.

Examining the equations in the preceding, we see that the expression of the current, counter E. M. F., etc., contains the impressed E. M. F. E_0 as factor, the torque, power output and power and volt-ampere input contain E_0^2 as factor, while the efficiency, power factor, apparent efficiency and torque efficiencies are independent of E_0.

That is, in an induction motor, the efficiency, power factor, apparent efficiency, torque efficiency, apparent torque efficiency at a given slip or speed, and thus starting torque per volt-ampere or watt input are independent of the impressed E. M. F.

The current and counter E. M. F.'s are proportional to the impressed E. M. F.'s.

The torque, power and volt-amperes are proportional to the square of the impressed E. M. F.

This obviously applies only as long as the iron is below saturation, which, however, is always the case.

Under torque, output, etc., are understood the values at the armature conductors disregarding friction. Since the friction is the same at different impressed E. M. F.'s, and the total output varies with the square of the impressed E. M. F., the difference, or the net mechanical output will be somewhat more than proportional to the square of the impressed E. M. F. On the other hand, at high impressed E. M. F.'s, that is greater output, the motor gets hotter, and thus its electric resistance rises and thereby reduces the output somewhat when running continuously.

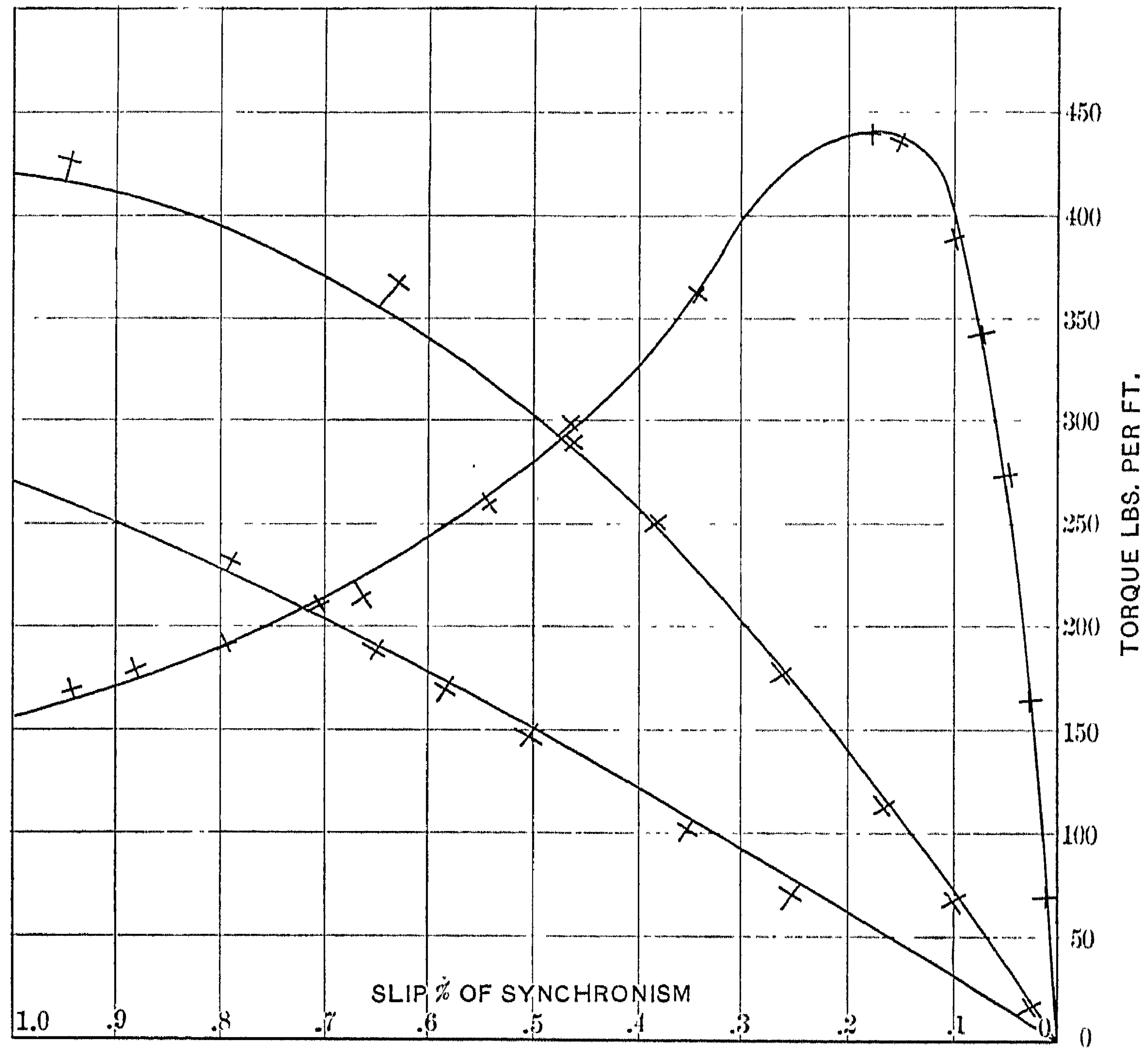


FIG. 2.
1.8-30-900-110, Form "A." 60 Cycles, 8 Poles, 110 Volts. Three Phase. Curves calculated with: $Y = .045 + .384j$; $Z_0 = .045 - .124j$; $Z_1 = .041 - .124j$. Friction: 510 Watts at Synchronism. Observed by Test: ×.

Rating the induction motor at a given percentage, say $\frac{2}{3}$ of maximum output or of maximum torque, the characteristic features of the motor are seen to be entirely independent of the impressed E. M. F. and merely dependent upon the admittance $Y_0 = g + j\,b$ and the impedances $Z_0 = r_0 - jx_0$, $Z_1 = r_1 - jx_1$.

A change of one of the impedances has comparatively little effect on the motor characteristic, provided that the other impedance is changed so that the total impedance $Z_0 + Z_1$ remains the same. Since the primary and the secondary impedance are generally fairly equal, except when intentionally made different, as by inserting high resistance in the secondary to get greater starting torque and greater drop of speed under load, or by inserting reactance in the primary to reduce the starting current and the starting torque, and since from tests of the motor only the sums of the impedances can conveniently be derived, but not the individual impedances, it is mostly sufficient to assume both impedances as equal.

$$Z = Z_0 = Z_1, \quad \text{or:} \quad Z = \tfrac{1}{2}(Z_0 + Z_1).$$

Hereby the induction motor is reduced to two complex imaginary constants Y and Z, or four real constants g, b, r, x, the same terms which characterize the stationary alternating current transformer on non-inductive load.

Instead of conductance g, susceptance b, resistance r, and reactance x, may be chosen as characteristic constants

the absolute admittance $y = \sqrt{g^2 + b^2}$,

the absolute impedance $z = \sqrt{r^2 + x^2}$,

the power factor of admittance $\beta = \dfrac{g}{y}$,

and the power factor of impedance $\gamma = \dfrac{r}{z}$.

If the admittance y is reduced n-fold and the impedance z increased n-fold, with the E. M. F. $\sqrt{n}\,E_0$ impressed upon the motor, the speed, torque, power input, and output, volt-ampere input and excitation, power factor, efficiencies, etc., of the motor, that is, all its characteristic features remain the same, as seen from above given equations, and since a change of impressed E. M. F. does not change the characteristics, as seen above, it follows that a change of admittance and of impedance does not change the characteristics of the motor, provided the product $\vartheta = 2\,y \times z$ remains the same.

Thus the induction motor is characterized by three constants only:

The product of admittance and impedance $\vartheta = 2\,yz$, which may be called the characteristic constant of the motor.

The power factor of primary admittance $\beta = \frac{g}{y}$.

The power factor of impedance $\gamma = \frac{r}{z}$.

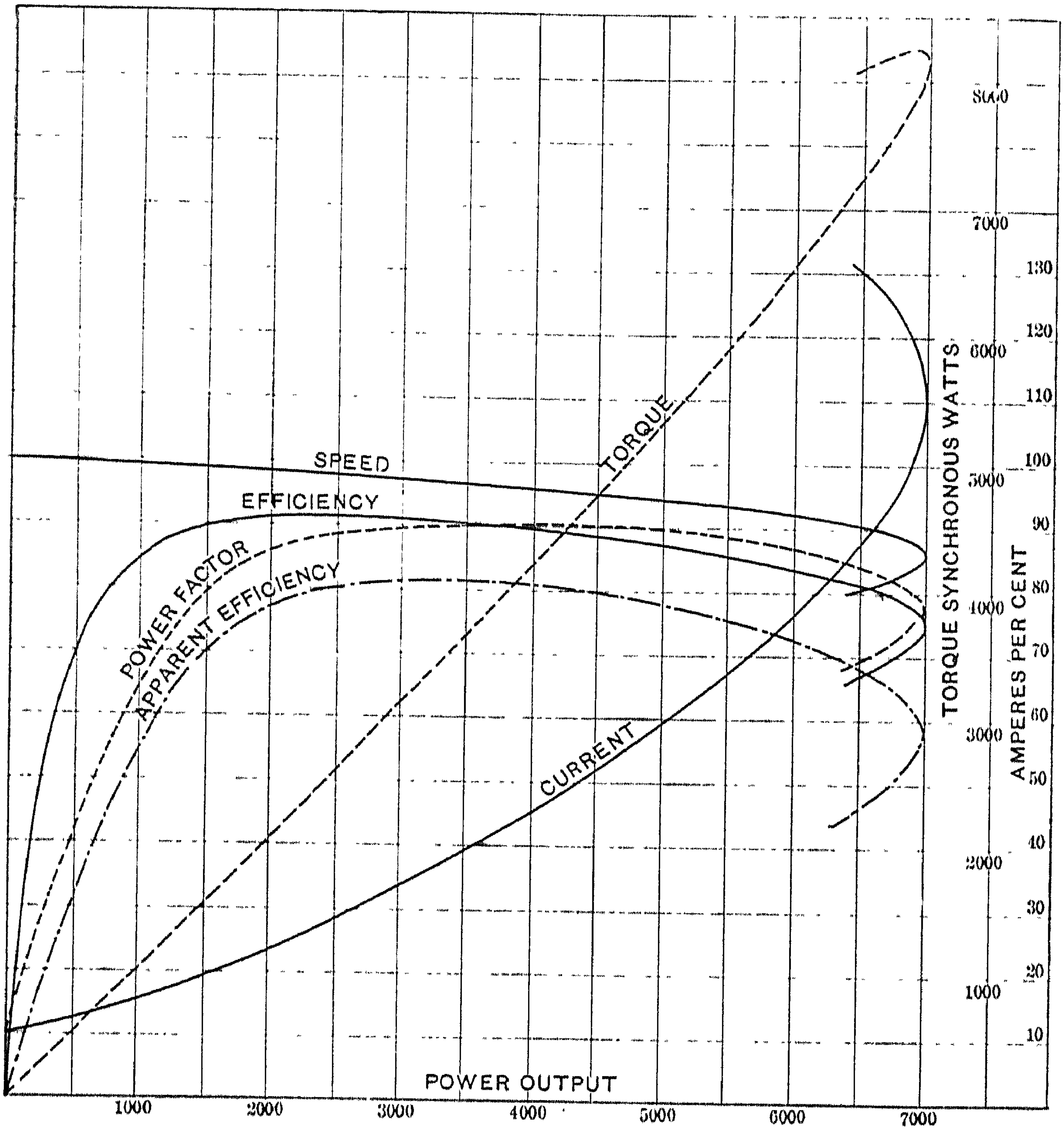


FIG. 3.—Induction Motor. Load Curves. $Z = .1 - .3j$. $Y = .01 + .1j$.

All these three quantities are absolute numbers.

The physical meaning of the latter two, the power factors, is obvious.

The physical meaning of the characteristic constant or the product of admittance and impedance is the following:

If I_{00} = exciting current,

I_{10} = current taken by the motor at stand still,

it is approximately

$$y = \frac{I_{00}}{E_0},$$

$$z = \frac{E_0}{2\,I_{10}},$$

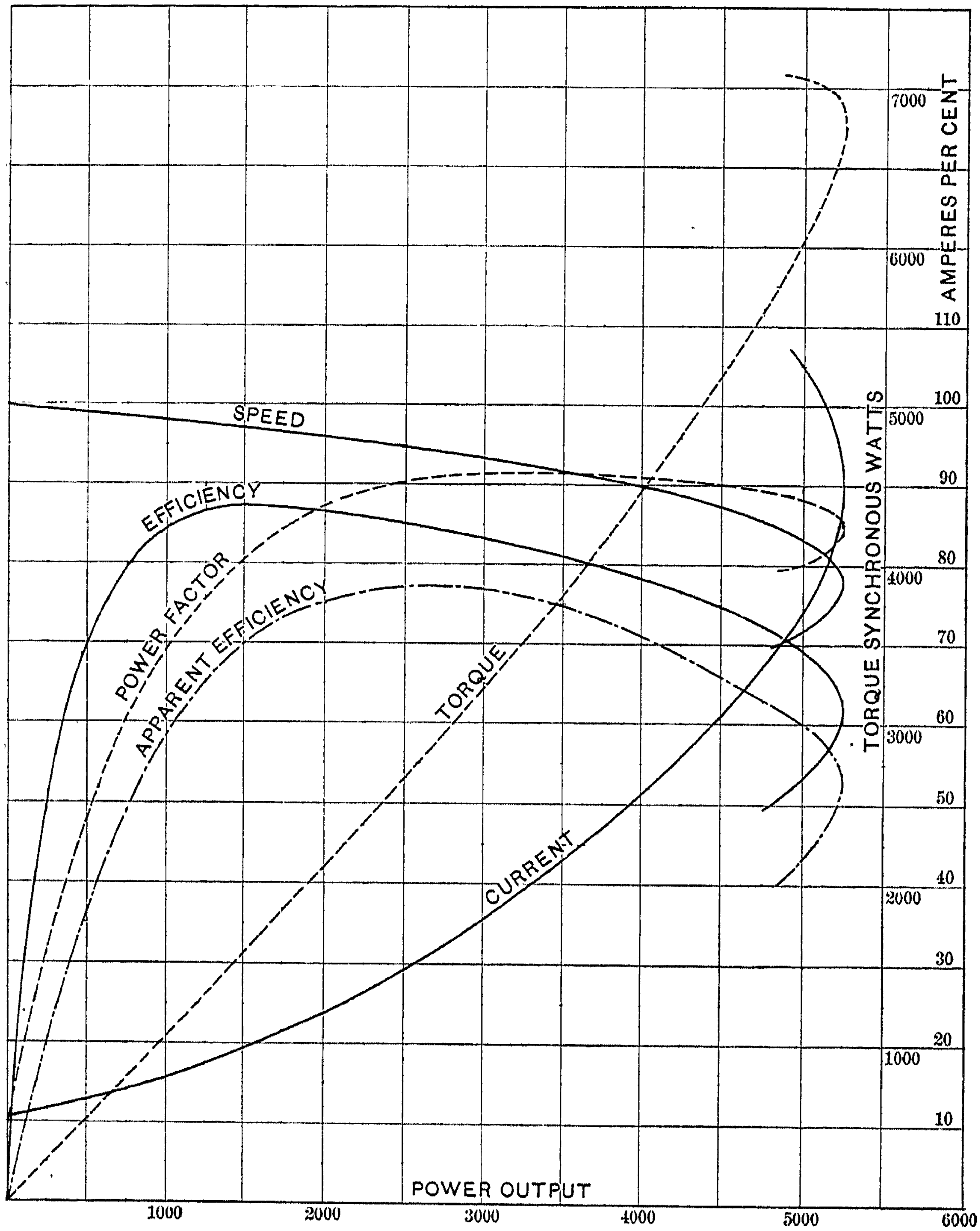


Fig. 4.—Induction Motor. Load Curves. $Z = .2 - .3j$. $Y = .01 + .1j$.

thus:

$$\vartheta = 2\,yz = \frac{I_{00}}{I_{10}}.$$

The characteristic constant of the induction motor $\vartheta = 2\,yz$ is the ratio of exciting current to short-circuited current.

At given impressed E. M. F., the exciting current I_{00} is inversely proportional to the mutual inductance of primary and secondary circuit. The short-circuited current I_{10} is inversely proportional to the sum of the self-inductance of primary and secondary circuit.

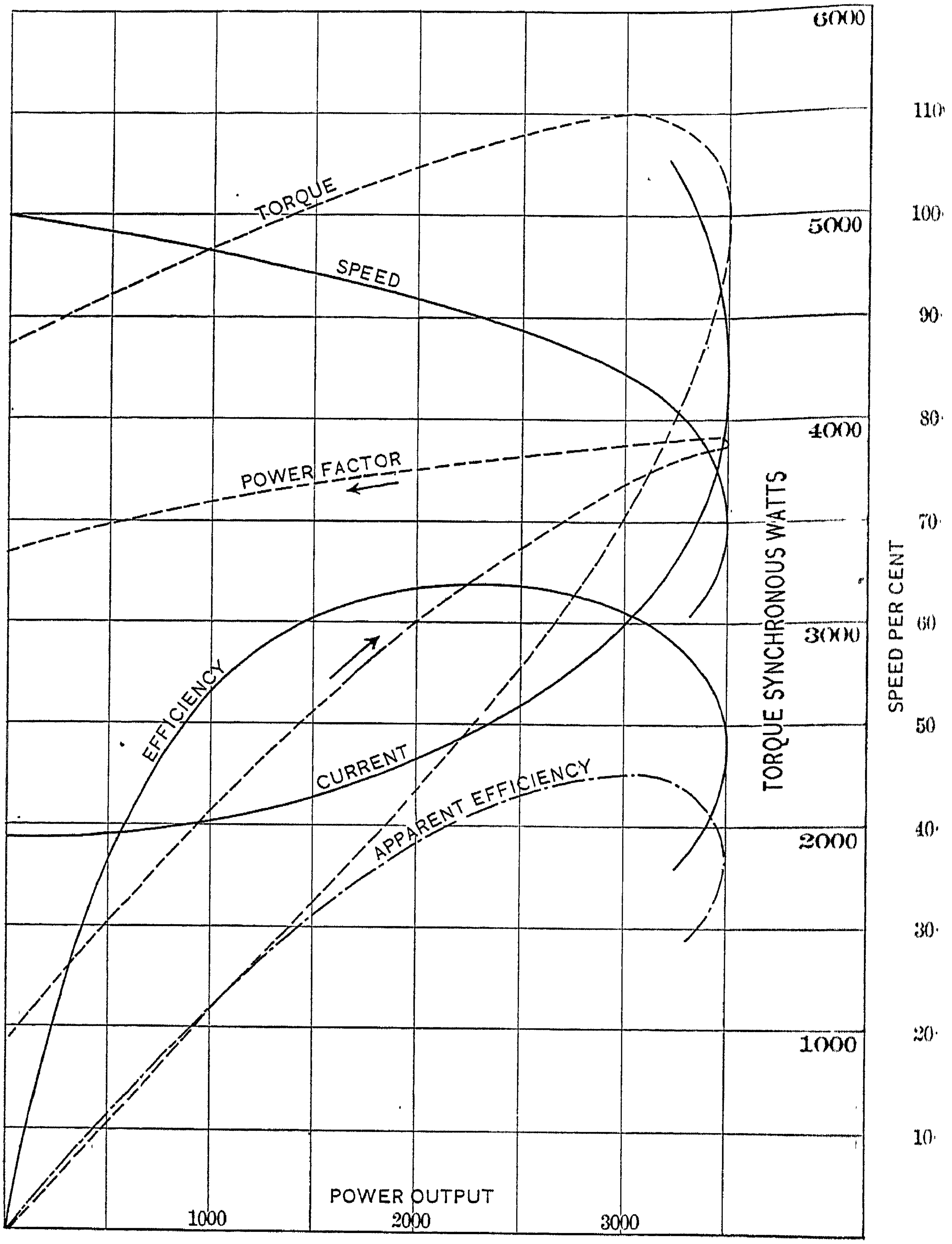


FIG. 5.—Induction Motor. Load Curves. $Z = .3 - .3j$. $Y = .04 + .4j$.

Thus the characteristic constant $\vartheta = 2\,yz$ is approximately the ratio of total self-inductance to mutual inductance of the motor circuits, that is, the ratio of the flux interlinked with one circuit, primary or secondary only, to the flux interlinked with both circuits, primary and secondary. The effect of this quantity will be shown in the following in the discussion of individual motors.

To exhibit the effect of the variation of constants on the behavior of the induction motor, a number of characteristic motors have been calculated in the above described manner, and the load curves of some of them are shown in Figs. 3 to 7, while an abstract of their constants is given on Table I.

These motors are calculated with the constants:

1st.—
$Y = .01 + .1j$,
$Z = .1 \quad - .3j$, or
$\vartheta = 6.36$,
$\beta = 10.0$,
$\gamma = 31.6$. Fig. 3.

2nd.—
High resistance motor.
$Y = .01 + .1j$,
$Z = .2 \quad - .3j$, or
$\vartheta = 7.26$,
$\beta = 10.0$,
$\gamma = 55.4$. Fig. 4.

3rd.—
High resistance and high admittance motor.
$Y = .04 + .4j$,
$Z = .3 \quad - .3j$, or
$\vartheta = 34.20$,
$\beta = 10.0$,
$\gamma = 70.7$. Fig. 5.

4th.—
High reactance motor.
$Y = .04 + .4j$,
$Z = .05 - .3j$, or
$\vartheta = 24.44$,
$\beta = 10.0$,
$\gamma = 16.4$. Fig. 6.

5th.—
High susceptance motor.
$Y = .02 + 4j$,
$Z = .1 \quad - .3j$, or
$\vartheta = 25.35$,
$\beta = 5.0$,
$\gamma = 31.6$. Fig. 7.

Number 1, with load curves shown in Fig. 3, refers to the best motor which can be built at frequencies of 40 to 60 cycles.

TABLE I.

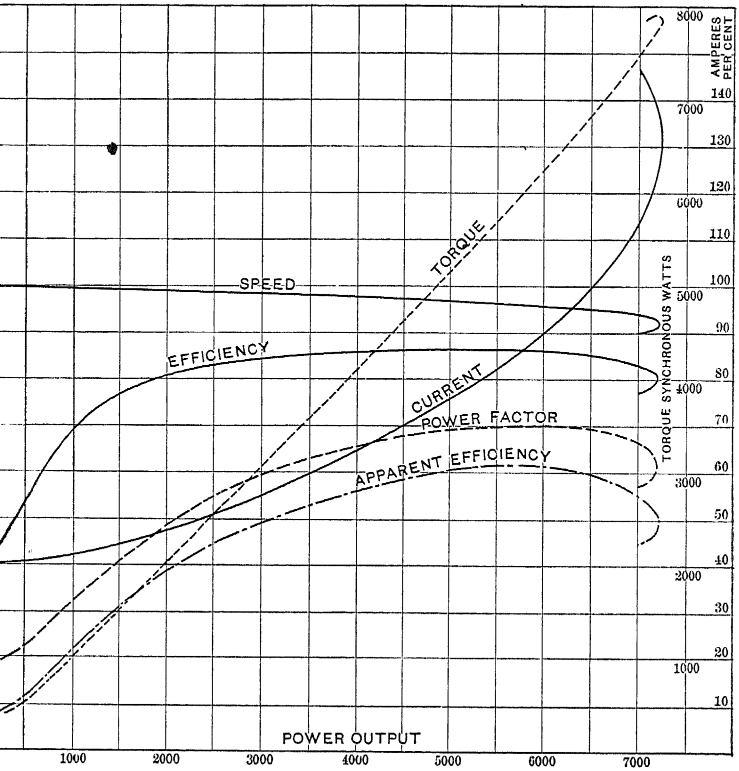
CONSTANTS OF INDUCTION MOTORS.

$E_0 = 110.$

(The motors marked by × are typical motors.)

No of motor.	No. of diagram.	$Y = g + jb$	$Z = r - jx$	$\vartheta = 2yz = y(z_0 + z_1)$	$\beta = \frac{g}{y}$	$\gamma = \frac{r}{z} = \frac{r_0 + r_1}{z_0 + z_1}$	T_m = max. torque, synchr. kilowatt.	P_r = rated output, kw. at ⅔ T_m.	P_m = max. output, in per cent. of P_r.	s = slip, at P_r	Exciting current, per cent. of current at P_r	Power Factor at			Efficiency at			Apparent efficiency at		
												full load.	½ load.	¼ load.	fu l load.	½ load.	¼ load	full load.	½ load.	¼ load.
		$.005 + .05j$	$.1 - .3j$	3.18	10.0	31.6	9.00	5.65	1.33	6.3	8.7	96.6	95	91	85	93	93.5	82.2	88	85
		$.01 + .1j$	$.05 - .3j$	6.12	10.0	16.4	8.90	5.75	1.42	3.2	16.7	88.7	88.7	77.8	92.4	93.5	90.8	82	83,1	70.5
×1	3	$.01 + .1j$	$.1 - .3j$	6.36	10.0	31.6	8.25	5.15	1.36	6.3	17.4	89	88.5	74	86.5	91.2	88.2	77.4	81	65
×2	4	$.01 + .1j$	$.2 - .3j$	7.26	10.0	55.4	7.10	4.20	1.25	11	19.5	91	88.4	71	76	86.5	85	69.2	76	60
		$.01 + .1j$	$.4 - .3j$	10.04	10.0	80.0	5.30	2.90	1.12	6 18	25.0	93	83	57	66	85	90	61	70	51
		$.02 + .2j$	$.1 - .3j$	12.70	10.0	31.6	7.90	4.95	1.35	6.3	32	83	74	55	84	87	80	70	64.5	44
		$.02 + .2j$	$.2 - .3j$	14·52	10.0	55.4	6.80	4.00	1.26	11	36	85	72	50,5	75.5	80.6	74	64.3	58 2	37.5
×4	6	$.04 + .4j$	$.05 - .3j$	24.44	10.0	16.4	7.90	5.10	1.42	3.2	51 4	69.4	55	37	86.4	83	73.5	60.5	45.5	27
×5	7	$.02 + .4j$	$.1 - .3j$	25.35	5.0	31.6	7.60	4.75	1.35	6.3	52	71	54	36	82	82.3	75	58.2	44.5	26
		$.04 + .4j$	$.1 - .3j$	25.40	10.0	31.6	7.30	4.55	1.35	6.3	53.5	71	54	36	79.7	79	69	56	42.5	25
×3	5	$.04 + .4j$	$.3 - .3j$	34.20	10.0	70.7	5.50	3.10	1.13	16.5	62.5	75	53	37	60.6	61.3	47	45.3	32.5	17
		Single	phase	Motors:																
1_1		$.03 + .3j$	$.1 - .3j$ $.033 - .1j$	12.72	10	31.6	9.9	6.4	1.43	2.8	36	82	73	52.5	84.5	85	78	70	61.5	40.5
2_1		$.03 + .3j$	$.2 - .3j$ $.067 - .1j$	14.52	10	55.4	7.5	4.8	1.36	4.3	44.3	85	67.5	47	74.5	78	69	62	53	33.5
4_1		$.12 + 1.2j$	$.05 - .3j$ $.0167 - .1j$	48.88	10	16.4	8.8	5.8	1.43	1.9	73	52	36	24.5	76	68	52	39.5	24.5	13
5_1		$.06 + 1.2j$	$.1 - .3j$ $.033 - .1j$	50.7	5	31.6	7.75	5.0	1.41	3.4	78	53.5	35	24	69.5	62.5	47.5	37	22	11
3_1		$.12 + 1.2j$	$.3 - .3j$ $.1 - .1j$	68.4	10	70.7	4.3	2.67	1.33	6.8	92	60.5	45.7	38.5	40	28.6	17	24.3	13.5	6.8

seen, the efficiency rises very rapidly at light loads, reaches a ximum of 91%, and then slowly drops to 88% at full load. The ver factor rises somewhat slower, but is already 74% at quarter d. The apparent efficiency is very high also, above 80%, and es at light loads quite rapidly. The exciting current is very ll. The drop of speed, 6%, at full load, could be made less lessening the armature resistance. In very large motors as



. 6.—Induction Motor. Load Curves. $Z = .05 - .3j$. $Y = .04 + .4j$.

e a speed regulation as 1 to 1½% has been reached. Thus this or is equally as satisfactory at light loads as at heavy loads.

umber 2 in Fig. 4 shows the typical *high resistance motor*. characterized by poor speed regulation, a drop of 11% at full ., an efficiency curve reaching very high values at light load, falling off with load, while the power factor rises slowly, but hes very high values at heavy loads. The apparent efficiency uite fair and the exciting current the same as in the first motor, thus due to the decreased output of this motor a somewhat higher percentage of full load current, when rating the motor at $\frac{2}{3}$ maximum torque.

If besides high resistance the motor has *high admittance* also, as number 3 in Fig. 5, the high efficiency maximum at light loads is cut off and the efficiency curve flattened and lowered. The power factor rises very slowly at light loads, reaching a lower maximum. Characteristic, however, remains the large drop in speed, while the exciting current has increased very greatly also.

If the high resistance is in the field or primary only, but the armature or secondary of low resistance, even the characteristic feature of poor speed regulation is less marked, and the high resistance recognized only by comparing efficiency, power factor, and speed curve.

The reverse, a *high reactance motor*, is motor number 4, shown in Fig. 6. Characteristic of this motor is the constancy of speed, 3.3% drop at full load, and especially the efficiency curve, which rises slowly, but reaches a fairly high maximum at or rather above full load. Power factor and apparent efficiency are low, with maxima beyond full load, and rise very slowly, that is, are poor at light loads. As seen, such a motor is in general unsatisfactory and may be less objectionable only in special cases, where it is running constantly at or near full load, or where very close speed regulation is required and wattless currents less objected to.

Number 5, in Fig. 7, shows a *high susceptance motor*. This motor is characterized by good efficiency at light loads as well as heavy loads, but power factor and apparent efficiency are very low at light loads and rise very slowly and reach their maximum only at or above full loads.

Comparing the different motors with each other, we see that a good motor is characterized by high values of power factor, efficiency and apparent efficiency at light loads as well as heavy loads, by fairly close speed regulation and low exciting current.

High resistance is characterized by *poor speed regulation* and lowering of the efficiency at heavy loads, *high reactance* by very good speed regulation, good efficiency at heavy loads, and low power factor and apparent efficiency at light loads, *high admittance* by high exciting current and poor power factor and apparent efficiency at light loads.

An abstract of the data of these motors and a number of other motors is given in Table I.

§ 2. *Speed Curves.*—The load curves discussed in the preceding are especially characteristic of the action of the motor when doing work at its proper speed near synchronism. The action in starting, or in running at intermediate speeds, or beyond synchronism, or when driven backwards, are best shown by what I may call the speed curves of the motor. A set of such curves,

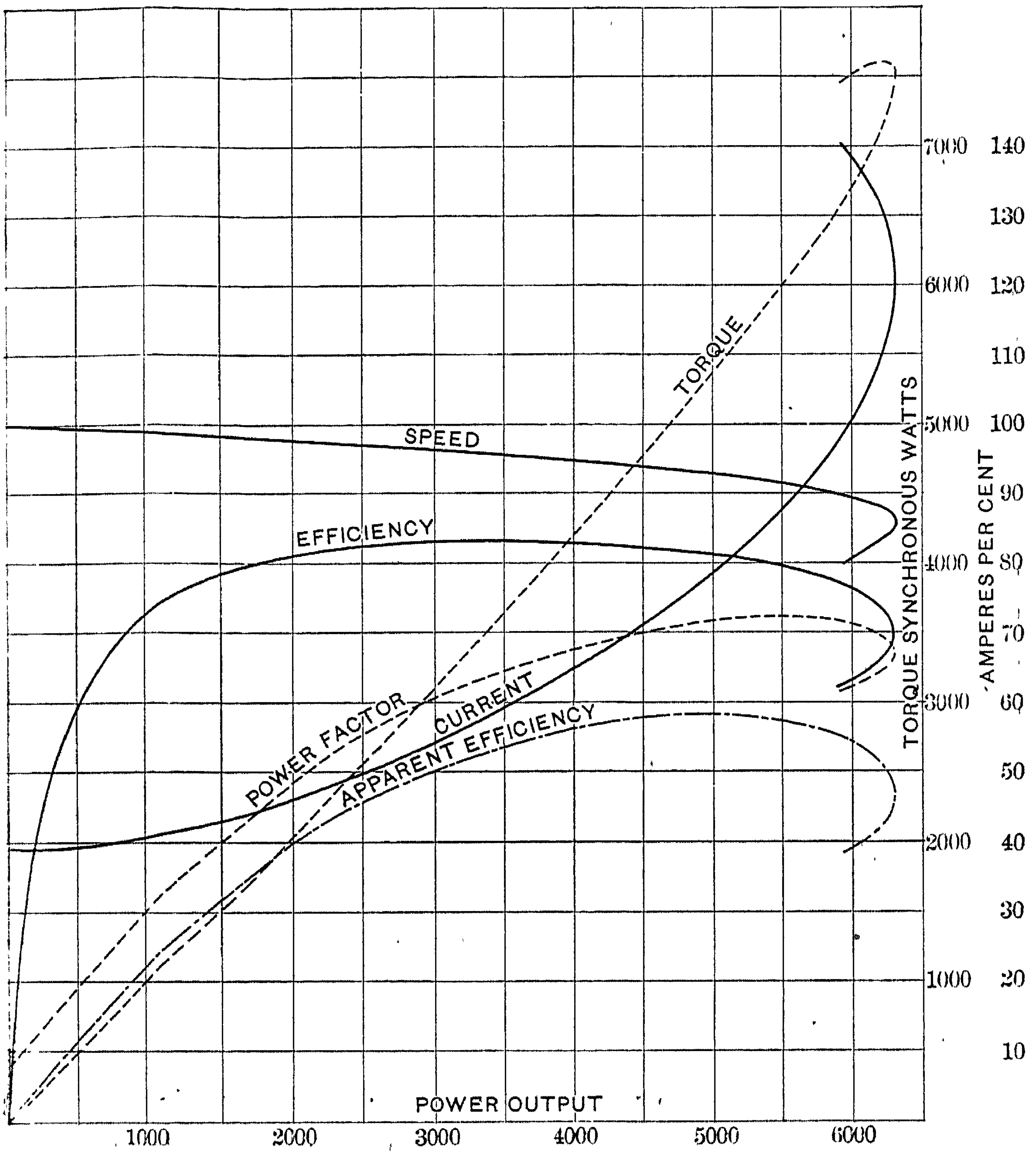


Fig. 7.—Induction Motor. Load Curves. $Z = .1 - .3j$. $Y = .02 + 4j$.

corresponding to the motor number 1 in Fig. 3, are shown in Fig. 8, of the constants

$$Y = .01 + .1j, \qquad Z = .1 - 3j.$$

These curves give with the speed, that is, the slip, as abscissae, the torque in watts at synchronism and the current input of the motor. As seen, the torque is zero at synchronism, increases with increasing slip, that is, decreasing speed, reaches a maximum of 8,250 synchronous watts at 16.5% slip, and then decreases again, reaching 2,920 synchronous watts at $s = 1$, that is, standstill, and keeps on decreasing for $s > 1$, that is, backward rotation, without change of direction, thus representing consumption of energy by the motor. For $s < 0$, that is, above synchronism, the torque curve is the counterpart of the torque curve for $s > 0$, but is negative, representing consumption of mechanical energy and thus production of electrical energy. It again reaches a maximum at $s = -16.5\%$, of 11,400 synchronous watts, and then decreases. The negative or generator part of the torque curve is higher than the positive or motor part, that is, driven as generator above synchronism the machine consumes more mechanical torque than it produces running as motor below synchronism.

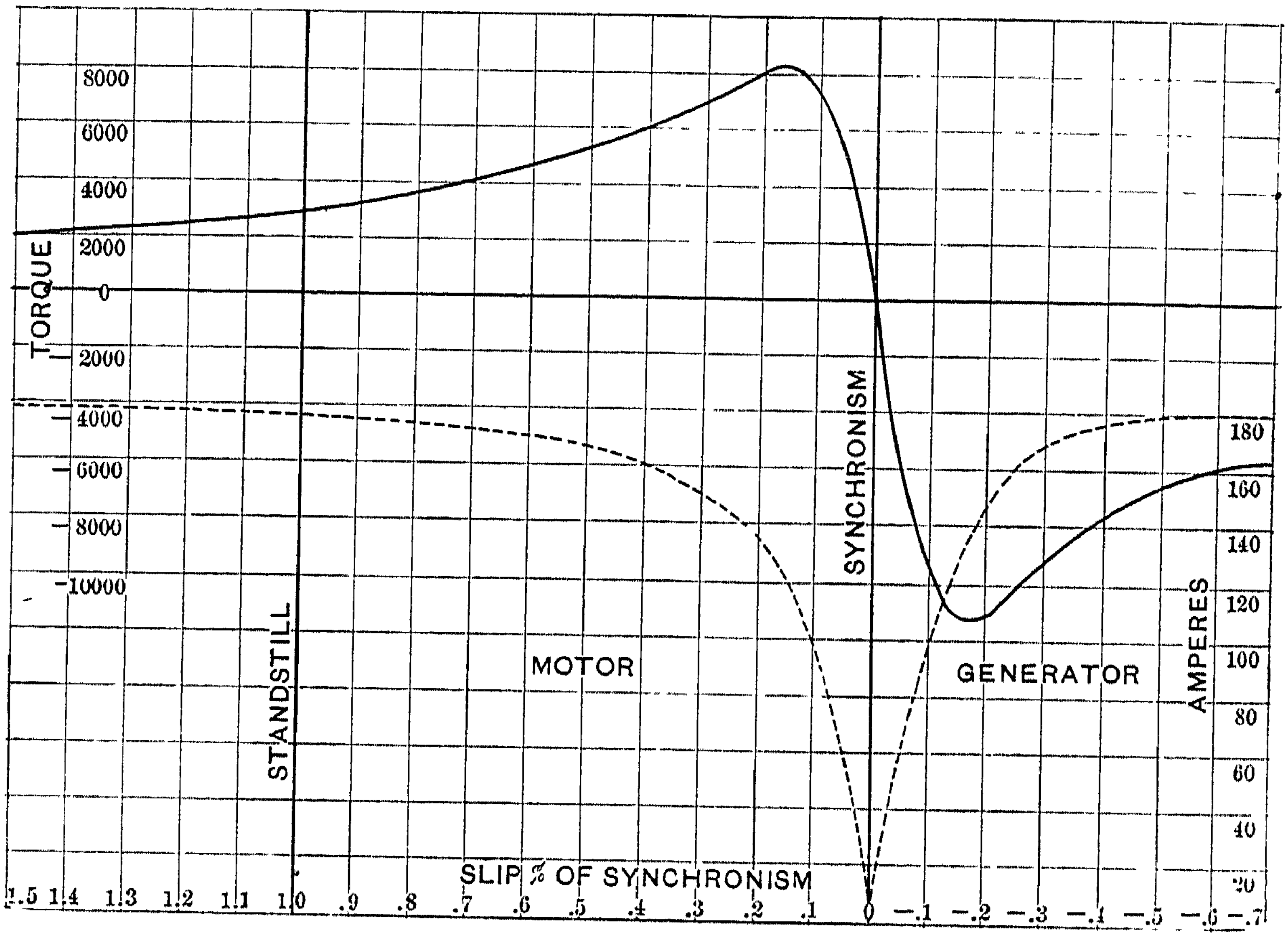


FIG. 8.—Induction Motor. Speed Curves. $Z = .1 - 3j$. $Y = .01 + .1j$.

Thus the induction motor shares with the continuous current shunt motor the feature to be a motor only below a definite speed, but to become generator or act as brake, by returning energy into the line, when driven above its speed.

The load curve of the motor corresponds to the part of the speed curve between synchronism and maximum torque at positive slip. From the part of the speed curve between synchronism and maximum torque at negative slip, or above synchronism, a corresponding load curve can be constructed of the machine as induction generator. This curve is shown in Fig. 9. As seen, it is very similar to the motor load curve, except that the speed curve bends upwards.

As generator the induction machine differs from the synchronous alternating current generator, or generator with constantly excited field, in-so-far as the latter can yield current and output at any power factor, that is, any phase displacement corresponding to the load, while in the induction generator at given terminal voltage to every value of current output a certain power factor of load corresponds. That is, to derive a certain value of current from the induction generator, the total load put on it must have the particular power factor corresponding to this current, and besides leading current, or if the power factor of the load changes, current and voltage of the induction generator will change accordingly. In consequence thereof, in general the induction generator is stable only, if at least a part of the load consists of synchronous motors.

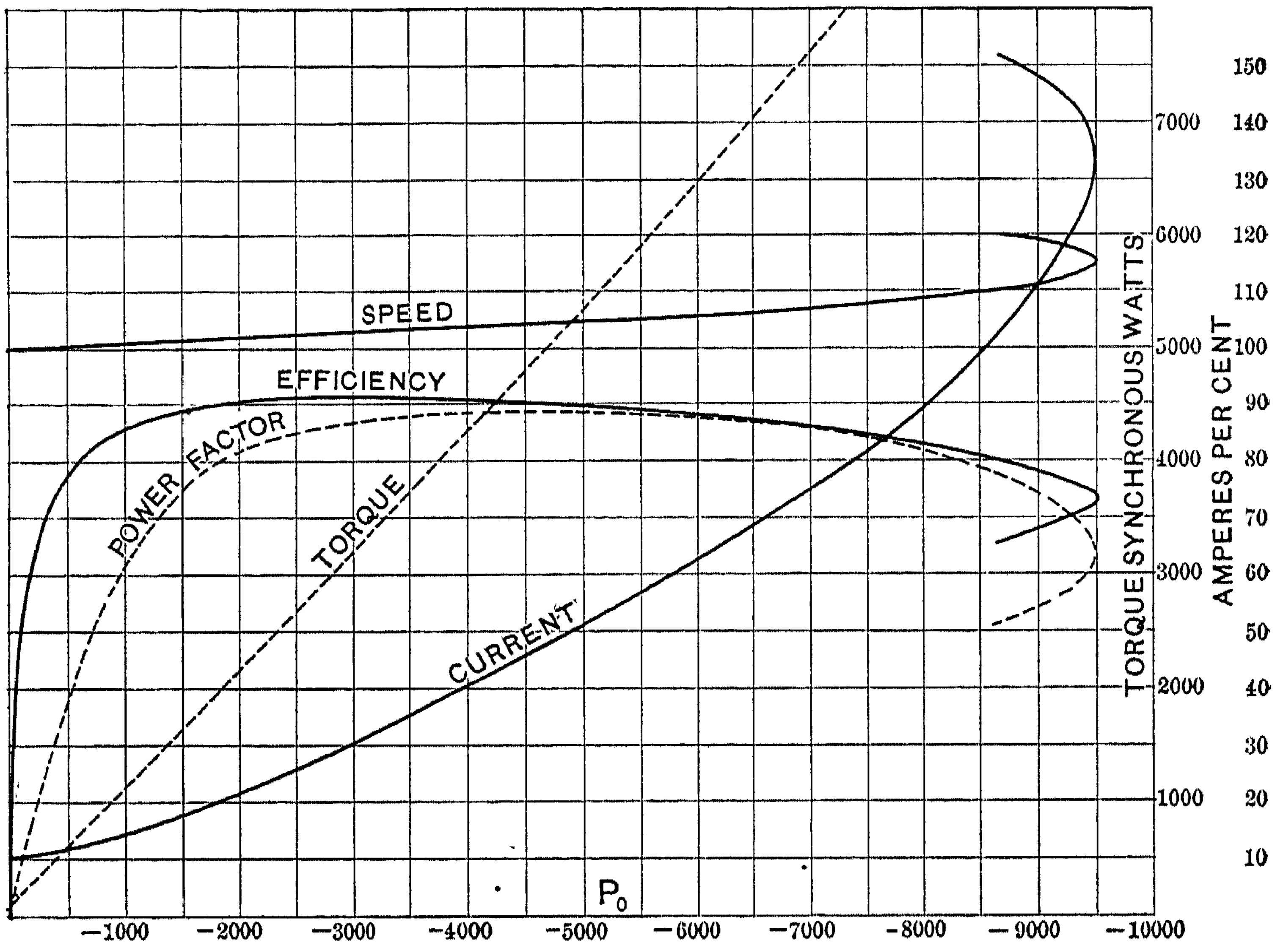


Fig. 9.—Induction Generator. Load Curves. $Z = .1 - .3j$. $Y = .01 + .1j$.

The current in the induction machine is a minimum at synchronism and decreases on either side of synchronism, first very rapidly and then slower, and becomes fairly constant afterwards, as seen in Fig. 8. In the particular motor under discussion, the whole variation of current is practically comprised within the range from $s = +.4$ to $s = -.3$, that is, the current at standstill is very large and remains practically constant until about $\frac{2}{3}$ of synchronous speed is reached. Thus such a motor with low armature resistance will require a very large current, not only in starting, but also at intermediate speeds.

Restricting our attention to that part of the torque curve below synchronism, we see that the torque curve consists of two branches, the upper branch from maximum torque to synchronism, and the lower branch from maximum torque to standstill. The same torque is reached on either branch; for instance, the torque of 4,800 synchronous watts at $s = .05$, and at $s = .6$. The currents corresponding to the two values of speed at the same torque are very different, however, 52.5 amperes on the upper, 171 amperes on the lower branch. On the upper branch the motor is stable, that is, with constant load runs at constant speed. On the lower branch, however, the motor is unstable and cannot maintain its speed, but must either slow down and come to standstill, or accelerate and reach the upper or stable branch, if loaded by constant torque.

In the same way above synchronism the machine as brake is stable between synchronism and maximum torque, and unstable beyond maximum torque.

As seen from the preceding, the motor number 1, while very satisfactory at speed, requires excessive current and gives little torque at low speed and in starting, and is thus unsatisfactory therein.

In the discussion of load curves in the preceding, we have seen that high resistance motors have a large drop of speed and thus reach a maximum torque point at lower speeds, that is, are in starting nearer to the maximum torque point, or in other words, have a greater starting torque.

From the equations of the induction motor it is obvious that this greater torque at low speeds is not due to the primary resistance, but exclusively to the secondary or armature resistance.

The armature resistance r_1 enters only in the equation of secondary current:

$$I_1 = \frac{s\,e}{r_1 - j\,s\,x_1} = e\left[\frac{s\,r_1}{r_1^2 + s^2\,x_1^2} + j\,\frac{s^2\,x_1}{r_1^2 + s^2\,x_1^2}\right] = e\,(a_1 + j\,a_2),$$

and in the further equations only indirectly in so far as r_1 is contained in a_1 and a_2.

Increasing the armature resistance n-fold, to $n\, r_1$ we get at an n-fold increased slip $n\, s$:

$$I_1 = \frac{n\, s\, e}{n\, r_1 - j\, n\, s\, x_1} = \frac{s\, e}{r_1 - j\, s\, x_1},$$

that is the same value, and thus the same values for e, I_0, T, P_0, ϑ, while the power is decreased from $P = (1 - s)\, \tau$ to $P = (1 - n\, s)\, T$, and the efficiency and apparent efficiency are correspondingly reduced. The power factor is not changed. Hence:

An increase of armature resistance r_1 produces a proportional increase of slip n, and thereby corresponding decrease of power, efficiency and apparent efficiency, but does not change the torque, current and power factor.

Thus the insertion of resistance in the armature or secondary of the induction motor offers a means to reduce the speed corresponding to a given torque, and thereby any desired torque can be produced at any speed below that corresponding to armature short circuit, without changing torque or current.

Hence, given the speed-torque curve of a short-circuited motor, the torque curve with resistance inserted in the armature can be derived therefrom directly by increasing the slip in proportion to the increased resistance.

This is done in Fig. 10, in which are shown the speed curves of the motor number 1 between standstill and synchronism, for:

Short-circuited armature: $r_1 = .1$.

.15 ohms resistance inserted in armature: $r_1 = .25$.

.5 ohms additional resistance inserted in the armature: $r_1 = .6$.

1.5 ohms additional resistance inserted in the armature: $r_1 = 1.6$.

The corresponding current curves are shown on the same sheet.

As seen, with short-circuited armature the maximum torque of 8,250 synchronous watts is reached at 16.5% slip. The starting torque is 2,950 synchronous watts, and the starting current 176 amperes.

With armature resistance $r_1 = .25$, the same maximum torque is reached at 40% slip, the starting torque is increased to 6,050 synchronous watts, and the starting current decreased to 160 amperes.

With armature resistance $r_1 = .6$, the maximum torque of 8,250 synchronous watts takes place in starting, and the starting current is decreased to 124 amperes.

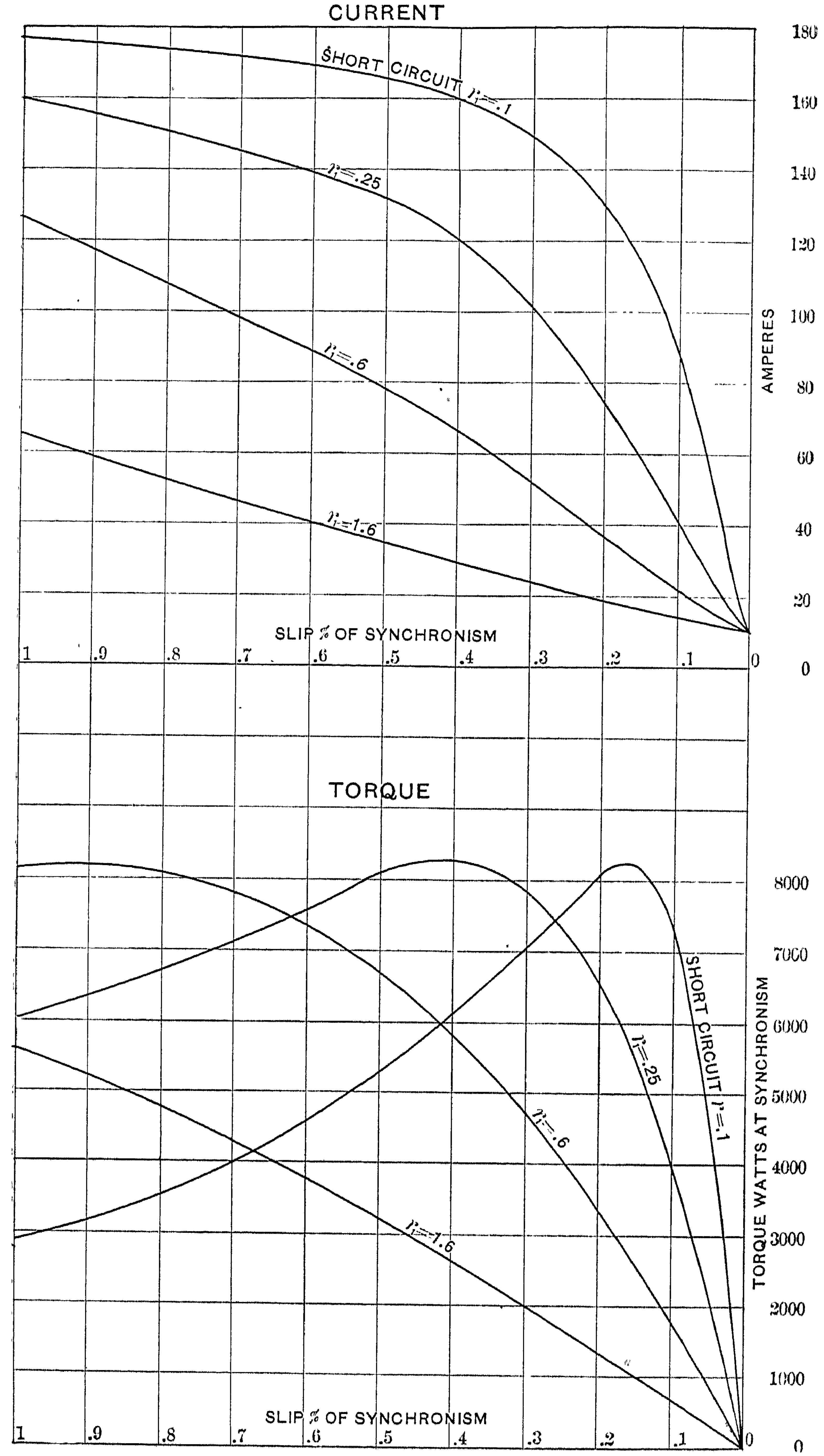


Fig. 10.—Induction Motor. Speed Curves. Torque and Current. $Y = .01 + .1j$. $Z = .1 - .3j$. Arm. Resistance: $r_1 = .1, .25, .6, 1.6$.

With armature resistance $r_1 = 1.6$, the starting torque is below the maximum, 5,620 synchronous watts, and the starting current is only 64 amperes.

In the two latter cases the lower branch of the torque curve has altogether disappeared and the motor speed is stable over the whole range, that is, the motor starts with the maximum torque which it can reach, and with increasing speed torque and current decrease, that is, the motor has the characteristic of the continous current series motor, except that it cannot race, but its maximum speed is limited by synchronism.

On the same diagram, Fig. 10, are shown the currents corresponding to the different values of secondary resistance.

The apparent torque efficiencies of the motor under the four conditions of armature resistance are given in Fig. 11. They show that, although a considerable starting torque can be reached by a moderate armature resistance, of $r_1 = .25$, the apparent torque efficiency or torque per ampere input is still very low under this condition, that is, the motor starts very inefficiently, and, as seen in the preceding discussion of high resistance motors, is rather inefficient at speed. The same diagram also shows the torque efficiencies. It follows herefrom that permanent resistance in the armature of an induction motor can be used to secure good starting torque at the sacrifice of current in starting, and of efficiency and speed regulation when running, but cannot be used to limit the starting current, the latter requiring so large an armature resistance as to make the motor entirely unfit when running.

This brings us to the investigation of the action of the induction motor in starting.

The condition in starting is $s = 1$.

Substituting $s = 1$ in the induction motor equations gives starting torque, current, power factor, etc.

$$I_1 = \frac{e}{r_1 - j\,x_1} = e\left[\frac{r_1}{r_1^2 + x_1^2} + \frac{j\,x_1}{r_1^2 + x_1^2}\right] = e\,(a_1 + j\,a_2)$$

$$a_1 = \frac{r_1}{r_1^2 + x_1^2} \qquad a_2 = \frac{x_1}{r_1^2\,x_1^2}.$$

$$I_{00} = e\,(g + j\,b).$$

$$I_0 = I_1 + I_{00} = e\,[(a_1 + g) + j\,(a_2 + b)] = e\,(b_1 + j\,b_2)$$

$$b_1 = a_1 + g \qquad b_2 = a_2 + b.$$

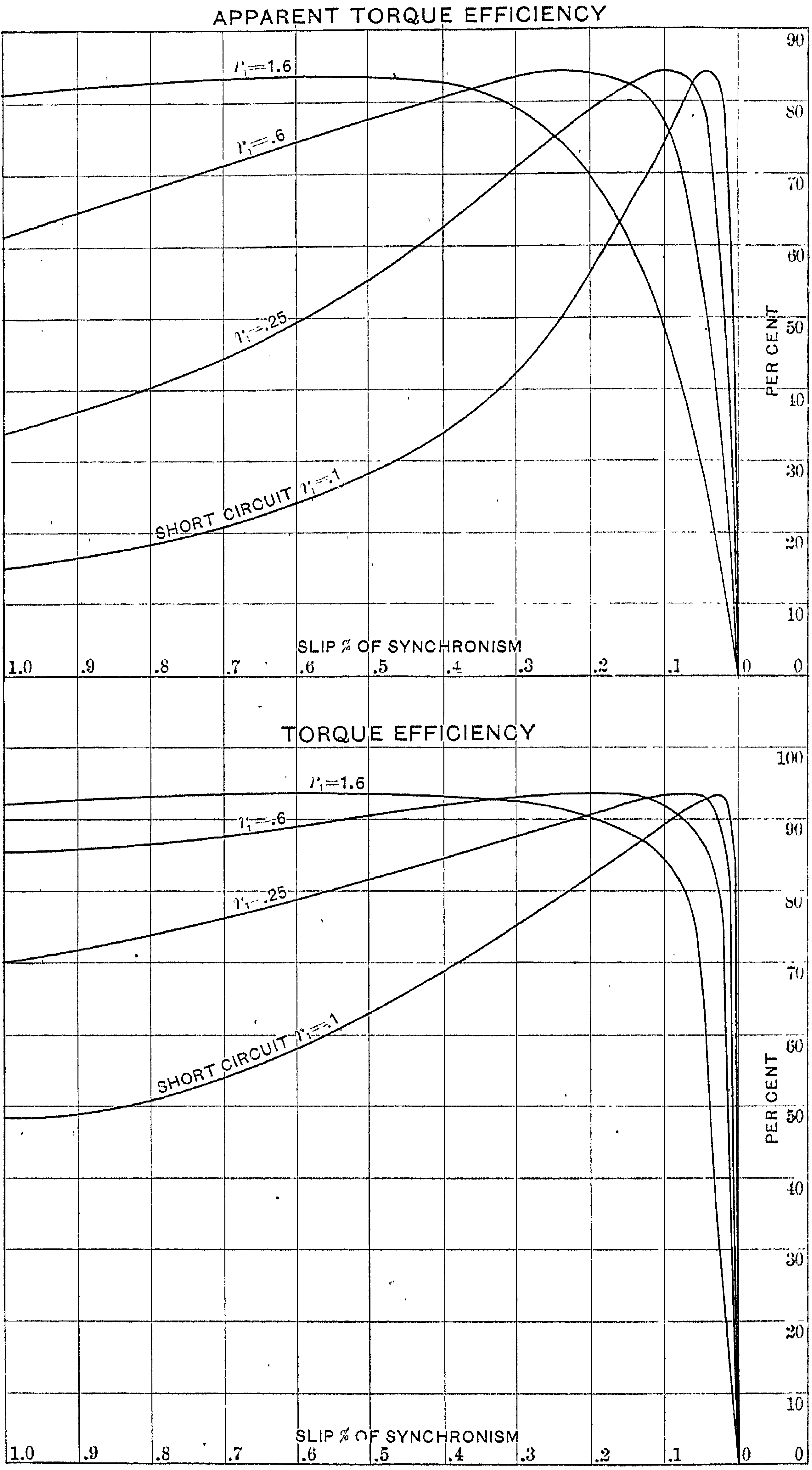


FIG. 11.—Induction Motor. Speed Curves. Apparent Torque Efficiency and Torque Efficiency. $Y = .01 + .1j$. $Z = .1 - .3j$. Armature Resistance. $r_1 = 1.6, .6, .25, .1$.

$$E_0 = e + I_0 Z_0 = e\,[1 + (b_1 + j\,b_2)\,(r_0 - j\,x_0)] = e\,(c_1 + j\,c_2)$$

$$c_1 = 1 + r_0\,b_1 + x_0\,b_2 \qquad c_2 = r_0\,b_2 - x_0\,b_1.$$

$$e = \frac{E_0}{\sqrt{c_1^2 + c_2^2}}.$$

$$I_0 = e\,\sqrt{b_1^2 + b_2^2}.$$

$$T = e^2\,a_1.$$

$$P_0 = [I_0\,E_0] = e^2\,(b_1\,c_1 + b_2\,c_2).$$

$$Q = I_0\,E_0.$$

$$\text{Power factor } \frac{P_0}{Q}.$$

$$\text{Torque efficiency } \frac{T}{P_0}.$$

$$\text{Apparent torque efficiency } \frac{T}{Q}.$$

From these equations are calculated for the motor number 1 of

$$Y = .01 + .1\,j,$$
$$Z = .1 \;\; - .3\,j,$$

e starting torque, current, and torque efficiencies at various esistances and reactances in the secondary and in the primary, d plotted in the diagrams, Figs. 12 and 13.

In Fig. 12 is given, with additional armature resistance R as scissae, the values of starting torque, starting current, power ctor, torque efficiency and apparent torque efficiency.

In Fig. 13 are given the corresponding values, with reactance serted in the secondary.

The insertion of resistance or reactance in the primary has ly the effect of decreasing the voltage at the motor terminals d thereby decreasing the torque in proportion to the square of e voltage at the motor terminals, and the apparent torque efficicy directly proportional to the voltage at the motor terminals; at is, is a very inefficient and unsatisfactory means of starting, d suitable by its simplicity only where no starting torque is quired, to limit the starting current. By the use of additional sistance in the armature or secondary in starting, torque can be oduced, as seen, with the same current, power factor and rque efficiencies as correspond to the same torque when running.

In Fig. 13, representing the effect of reactance in the secondary circuit, the torque, current, etc., are shown for positive values or reactive coils, as well as negative values or condensers.

As seen, by the insertion of reactive coils in the secondary of

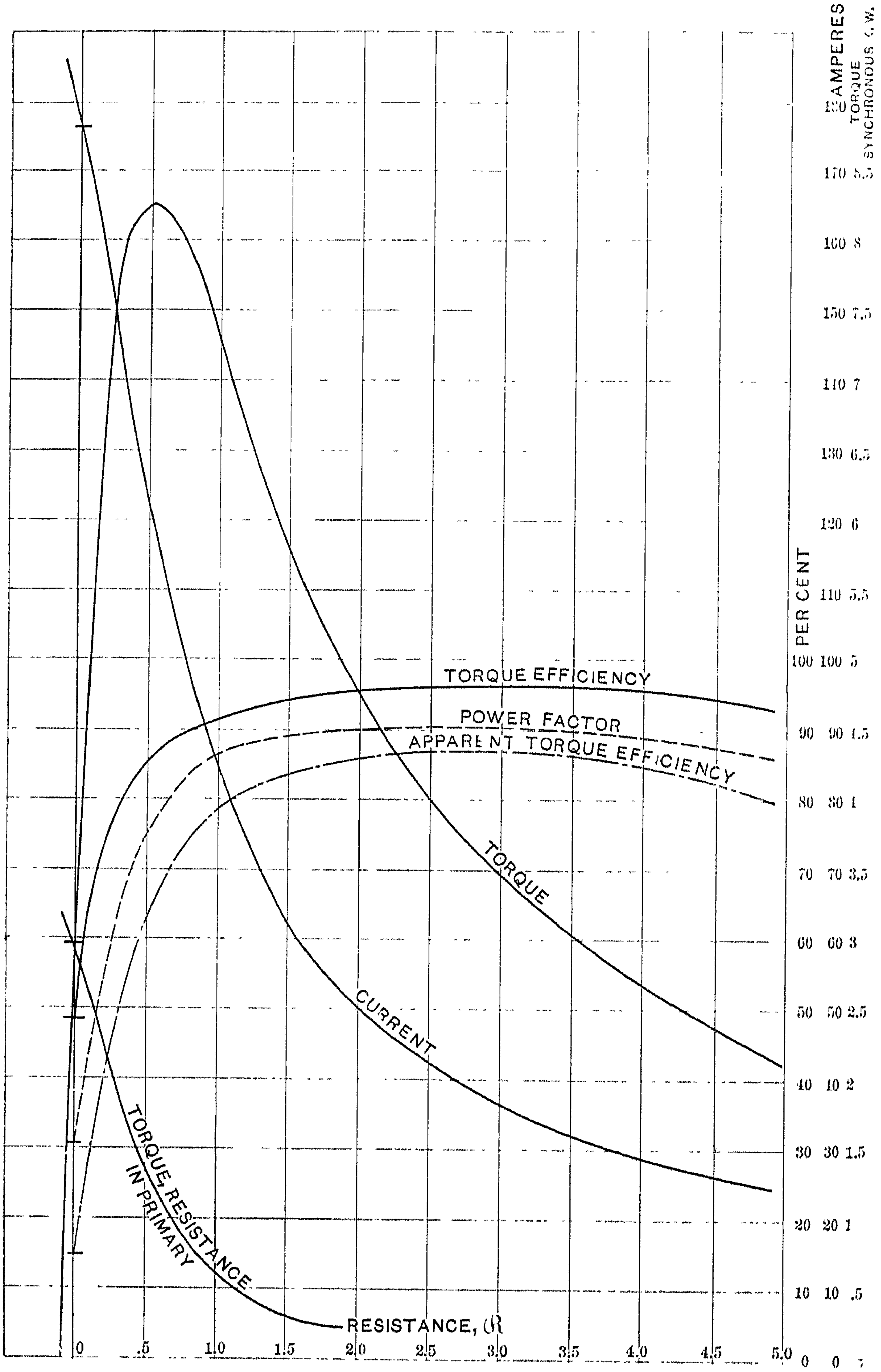


Fig. 12 —Induction Motor. Starting Torque, Current, Efficiencies and Power Factor. $Y = .01 + .1 j$. $Z = .1 - .3 j$. Resistance in Armature.

the induction motor, the torque decreases rapidly, and the effect of secondary inductive reactance is practically identical with that of the insertion of reactance in the primary circuit, that is, the use of inductive reactance in the armature, or the secondary is of no practical value.

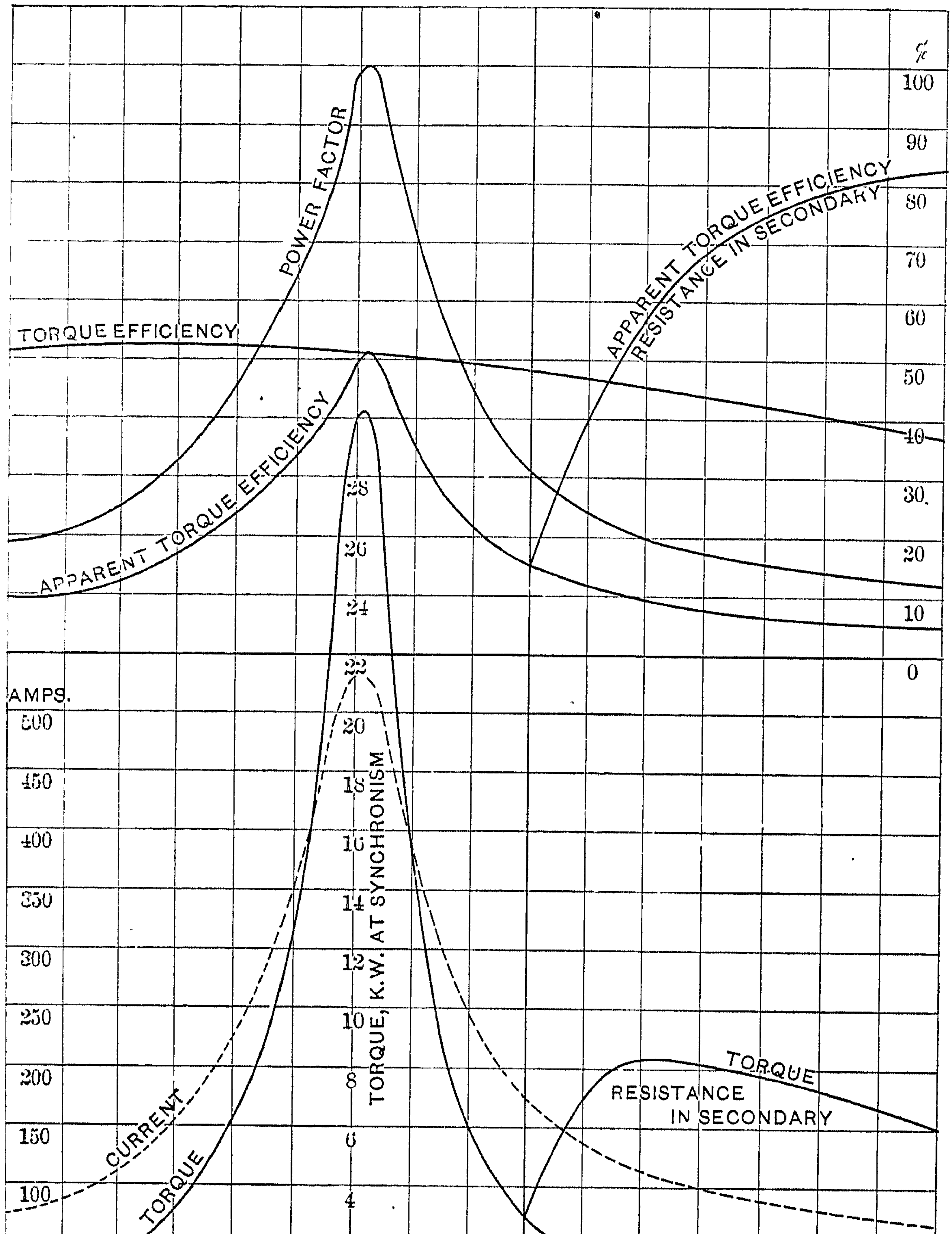


FIG. 13.—Induction Motor. Starting Torque, Current, Efficiencies and Power Factor. $Y = .01 + .1j$. $Z = .1 - .3j$. Reactance in Armature.

By the insertion of negative reactance or capacity, however, torque and current of the motor rise enormously, reaching a maximum of 30,200 synchronous watts and 530 amperes at —.58 ohms additional capacity reactance, that is, 3.66 times the maximum torque available with armature resistance, at 4.22 times the current corresponding thereto. At this point the power factor is 100%, that is, the current in phase with the impressed E. M. F. On one side of this point the current leads, on the other it lags. Torque efficiency, however, and apparent torque efficiency with the use of capacity in the secondary are very low, the torque efficiency in the whole range being about 50%, while by the use of resistance in the armature a torque efficiency considerably above 90% is reached. That means, capacity in the secondary, outside of the general inconvenience of the condenser, is far inferior in starting, to the use of non-inductive resistance, except in-so-far as the maximum available torque is far larger. But the current corresponding to this torque is far beyond the carrying capacity of the motor, and where such an excessive torque should be required, it could much more efficiently, that is, with a relatively lesser expenditure of current, be secured by varying the voltage impressed upon the motor by means of a potential regulator or transformer of variable ratio of transformation. By such a potential regulator the starting torque of the motor can be changed in any desired manner without a change of torque efficiency, etc., that is, the current input at primary side of the potential regulator will vary proportional to the torque developed by the motor.

§ 3. *Regulation and Stability.*—In the preceding, the load curves and speed curves of the polyphase induction motor, that is, the dependence of the electrical and mechanical features upon the output and the speed, have been discussed under the assumption of constant voltage at the motor terminals.

In practice, however, this condition is usually only approximately fulfilled. In general, the voltage in any alternating current system is maintained constant, or approximately so, at the centre of distribution or at the primary terminals of the transformers. Thus, between the motor terminals and the point of constant voltage of the system, a certain impedance exists in the circuit.

If now, as it is reasonable to expect, the distribution voltage, ratio of transformation, etc., are chosen so as to bring the rated voltage at full load at the motor terminals, at light load the voltage at the motor will be high, and thus the exciting current greater than at the rated voltage. Inversely at overload the voltage at the motor terminals will drop below the rated voltage, and thus the maximum torque and the maximum output of the motor be decreased in proportion to the square of the reduced voltage, that is, the more, the greater the impedance of lines, transformers, etc., is.

Thus, when operated under these conditions of practice, the induction motor does not give the same margin of overload as when operated at constant impressed voltage.

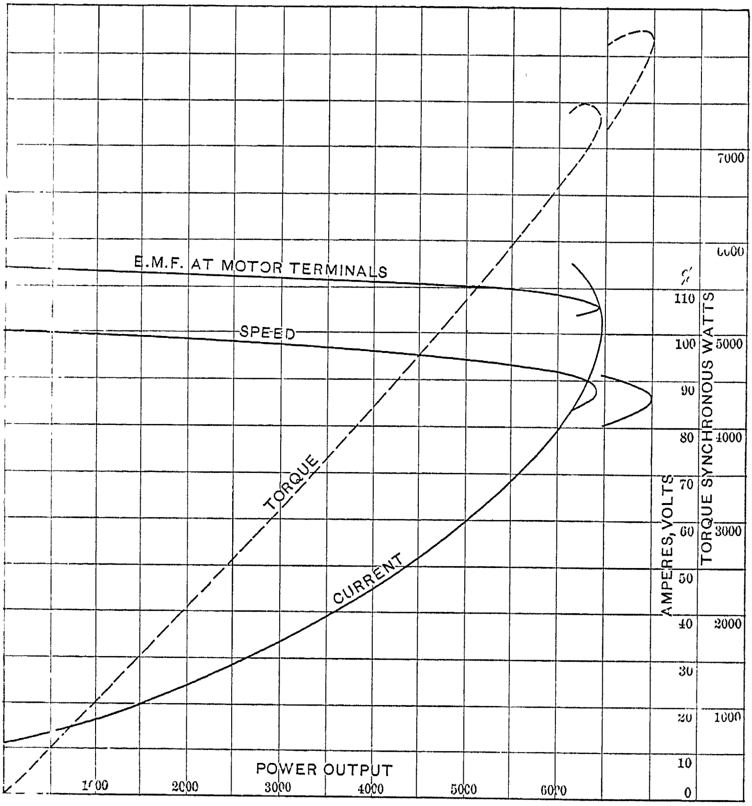


FIG 14.—Induction Motor. Load Curves. $Y = .01 + .1 j$. $Z = .1 - .3 j$. perated from transformers of impedance, $Z = .04 - .08 j$, at constant primary otential of 114.1 volts, corresponding to 110 volts at motor terminals at 5000 atts load.

This at once shows the desirability of designing the induction notor with sufficiently large margin of overload, and the necesity of choosing the supply circuit, and especially the transformrs, of as low impedance as possible.

As an instance are shown, in Figs. 14 and 15, the load curves of the motor discussed in the preceding, of the constants:

$$Y_0 = .01 + .1\,j,$$
$$Z = .1 - .3\,j,$$

rated at 5,000 watts per circuit full load, corresponding to 59 amperes at 110 volts impressed, when operated:

1) At constant impressed voltage of 110 volts. (Fig. 3.)

2) Operated from transformers of 2% resistance drop and 4% internal reactance, that is, transformers representing about the best make on the market, of very close regulation. (Fig. 14.)

3) Operated from transformers of 2% resistance drop and 15% internal reactance, or about the average type of cheap transformers, at constant primary voltage corresponding to 110 volts at full load at the motor terminals. (Fig. 15.)

In these cases, the impedance interposed between motor and point of constant voltage is:

$Z = .04 - .08\,j$, with best regulating transformers.

$Z = .04 - .3\,j$, with transformers of poor regulation.

In Figs. 14 and 15, the load curves of the motor, the limits of speed and torque curve at constant voltage of 110 are plotted also, showing that the maximum output is reduced under these conditions from 7,000 watts per circuit to 6,450 and 5,780 watts, respectively, and the maximum torque from 8,250 synchronous watts to 7,500 and 6,460, respectively.

That is, even with the best make of transformers inserted in the circuit, at constant voltage at their primaries and rated voltage at the motor terminals at full load, the margin of overload power is reduced from 40% to 29%, or by 11% in the instance chosen here, and the margin of overload torque from 55.5% to 41.5%, or by 14%, while an inferior type of transformers, of poor regulation, reduces the margin of power to 15.6% and the margin of torque to 22%, that is more than twice as much as transformers of close regulation. In consequence thereof, with transformers of poor regulation the motor is at full load already dangerously near the maximum output point, although at constant impressed voltage it has ample margin to carry any reasonable overload.

Still greater is the decrease of voltage, and thus of torque, in starting, especially with low resistance armature, due to the large currents consumed under these circumstances. With an armature containing a variable resistance of sufficient size, limiting the starting current, the starting torque is less affected by the transrmer. Thus, with short-circuited armature, in the motor osen as instance, the starting torque and starting voltage drop om 2,950 synchronous watts at 110 volts to 2,420 synchronous tts at 99.5 volts with good transformers, and only 1,635 synronous watts at 82 volts with poor transformers, while the rting current is correspondingly decreased from 176 amperes 139 and 131 amperes, respectively, but the exciting current, or

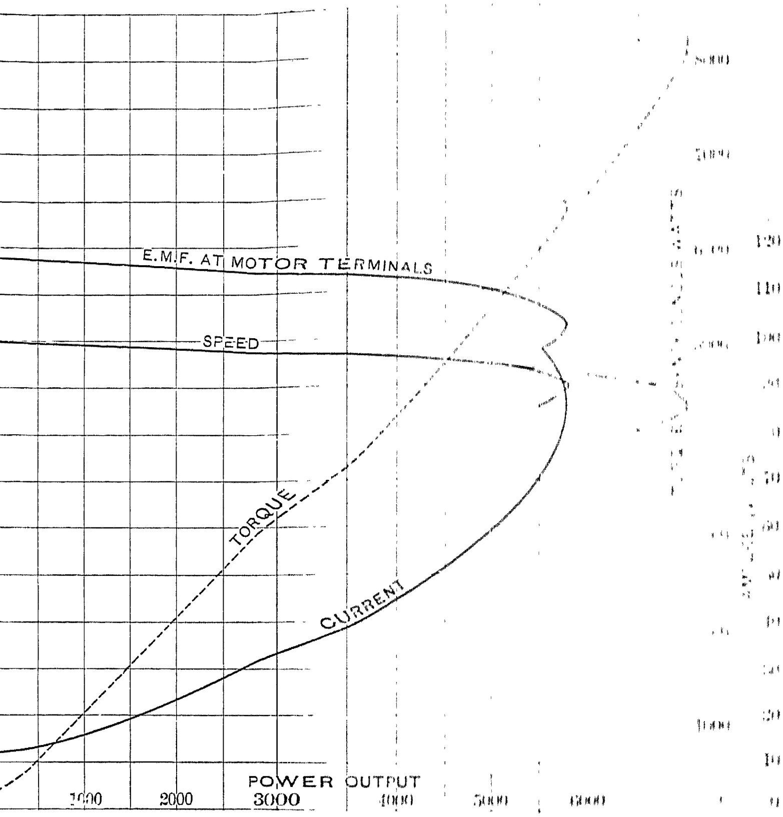


Fig. 15.—Induction Motor. Load Curves. $Y = .01 + .1j$. $Z = .1 - .3j$. erated from transformers of impedance, $Z = .04 - .3j$, at constant primary ential of 121 volts corresponding to 110 volts at motor terminals at 5000 tts load.

rrent, when running light, increased from 10.7 to 11 and 11.45 peres, respectively, due to the increase of voltage at light load. In consequence thereof, the characteristic constant, which is proximately equal to starting current divided by current at ndstill, is increased from 6.1% at constant impressed voltage to 6.9% with good, and 8.75% with poor transformer, with the result that the motor becomes inferior in every respect in correspondence with the increase of the characteristic constant ϑ, as discussed in the preceding. For instance, the exciting current rises from 17.4% to 20 and 24.7% of the current at $\frac{2}{3}$ maximum torque.

If in the installation of the motor the mistake is made not to allow for the drop of voltage taking place even in the best transformers on inductive load, but the ratio of transformation is chosen so as to give the rated motor voltage at the secondary terminals of the transformers at open circuit, output and torque of the motor are still further reduced, and even with the best transformers the margin of overload is only 19.4% in power and 31% in torque, while with transformers of poor regulation no margin of torque is left, and the motor cannot carry full load any more. That is, at constant primary voltage corresponding to the rated motor voltage at open circuit at the secondary terminals, the motor can be operated successfully only with the best type of transformers. This fundamental importance of transformer and line impedance on the operation of the induction motor has frequently been overlooked. It is, however, analogous to the dropping of torque and output of a continuous current motor, if the impressed voltage drops.

The curves are calculated thus:

Let at slip s the current in the motor $= i$ at the impressed E. M. F. e, and the angle of lag $= \varphi$. It is then the apparent impedance of the motor, in absolute value:

$$z_m = \frac{e}{i},$$

or in compress expression:

$$Z_m = \frac{e}{i}(\cos\varphi - j\sin\varphi).$$

If

$$Z = r - j\,x$$

equals the impedance of the transformer, etc., the total impedance of the system of motor, transformer, etc., is:

$$Z^1 = \left(r + \frac{e}{i}\cos\varphi\right) - j\left(x + \frac{e}{i}\sin\varphi\right),$$

or, absolute:

$$z^1 = \sqrt{\left(r + \frac{e}{i}\cos\varphi\right)^2 + \left(x + \frac{e}{i}\sin\varphi\right)^2}.$$

ull load, it is:

$$e = e_0, \qquad i = i_0^1,$$

:

$$z^1 = Z_0^1 = \sqrt{\left(r + \frac{e_0}{i_0^1} \cos \varphi_0\right)^2 + \left(x + \frac{e_0}{i_0^1} \sin \varphi_0\right)^2},$$

$$= i_0^1 z_0^1 = i_0^1 \sqrt{\left(r + \frac{e_0}{i_0^1} \cos \varphi_0\right)^2 + \left(x + \frac{e_0}{i_0^1} \sin \varphi\right)^2},$$

nstant primary impressed voltage of the system; thus, if s and voltage e_0 the current $i = i_0$, the motor imped-

:

$$z_m = \frac{e_0}{i_0},$$

e voltage at the motor terminals:

$$e = e_0^1 \frac{z_m}{z_1},$$

e motor current has to be changed in the proportion:

$$\frac{e}{e_0};$$

tor output and torque in the proportion:

$$\left(\frac{e}{e_0}\right)^2.$$

DISCUSSION.

THE PRESIDENT:—We are greatly indebted to Mr. Steinmetz for giving us these very definite and complete figures. The induction motor is a new piece of electric mechanism, and data, particularly such data as this, concerning it, are very valuable. He not only considers the ordinary type of motor, but also, the effect on the efficiency, torque, speed, etc., when the various factors such as resistance, impedance, etc., are exaggerated. The paper is open for discussion.

PROF. ELIHU THOMSON:—Mr. Steinmetz has given a vast amount of study to the problem of induction motors. I can say that he has done a good thing in giving the results of the work to the world, so that it may serve as a guide to others working on this general subject. The paper is full of material which requires a good deal of time and study to discuss, and I look forward to the time when in these other promised papers we shall see the rest of the matter presented. The subject is likely to be an exhaustless one, as the number of changes which can be rung upon this type of apparatus and similar types is almost endless. I simply call attention to what seems to me quite an interesting matter, which would be of course naturally expected, that is comparing Fig. 3 with Fig. 9, one machine run as a motor simply, and the other as an induction generator; we see the speed curves are almost the exact counterpart reflected upward, while the other curves are very much the same, and the breakdown line is marked in very much the same way, by a re-curving backward at a certain elevation above, and below in the other instance. No doubt further inspection of these very interesting curves would discover other analogies between the work of the different motors and under the different conditions.

THE PRESIDENT:—The use of an induction motor as a generator is a very interesting subject, about which there is not very much information now available. Mr. Steinmetz simply considers it incidentally in order to complete the scope of his investigations. The stability of their action is very peculiar, and he does not specify the exact conditions, but indicates them. I hope that point will be more fully covered in future papers.

PROF. W. E. GOLDSBOROUGH:—It seems to me that one of the most interesting points which the paper brings out is the great exactness with which a piece of apparatus can be designed. The curves which are shown in this paper, especially those of Figs. 1 and 2 are particularly valuable to us, in view of the fact that they indicate that a piece of electrical apparatus can be designed with as great, if not greater, accuracy than can any other kind of machinery. The points fall upon the curves with great exactness, and if I understand Mr. Steinmetz aright, the curves were figured out before the machine was operated. I do not know of any other case where the accuracy of the calculations made previous to the test of the machine has been anything like as marked as in the case we have before us, and this agreement between theory and practice seems to be something that is worthy of being emphasized.

Dr. A. E. Kennelly:—I think this paper is both interesting and important. It shows that the quantitative behavior of the induction motor depends on two vector quantities; so that, when these vectors are known, all the behavior of the motor can be predicated.

I am desirous of clearing up two points in the paper that seem to be open to misapprehension. On page 193 it is stated that the characteristic features of the motor depend merely upon its admittance and impedance. But unless otherwise defined, the admittance and impedance of a motor or any conducting circuit should be mutually reciprocal quantities, whereas this admittance and impedance are not apparently so connected, and it appears, in fact, that the impedance is exclusive of the mutual inductance of the machine, while the admittance includes it. It seems important to have this distinction pointed out.

As regards the term "torque-efficiency," the definition given in words on page 190, seems to be excellent and one much needed: namely, the ratio of the torque which a motor develops at a given intake, to the torque it would develop if it had no losses of energy. The symbolic definition for the torque efficiency on page 189, I do not understand, because it is expressed as a ratio of a torque to a power. It is true that torque and power have the same dimensional formula in our existing system of dimensions, but, we are accustomed to define an efficiency as the ratio of two quantities of the same nature, and not of two quantities of different natures. I think Mr. Steinmetz will assist us by clearing up this point.

Dr. F. A. C. Perrine:—I do not know whether I misunderstood Mr. Steinmetz or not, in reference to Fig. 13, page 211. If I did not, I cannot see how his statement agrees with the figure. It is stated that in spite of the fact that by the introduction of capacity the torque was tremendously increased, at the same time the torque efficiency was so largely decreased, that the effect of capacity was rather harmful than beneficial, and that instead of introducing capacity in order to get a high torque we should raise the voltage. The apparent torque efficiency certainly has a maximum coincident with the maximum of torque where the capacity reactance is introduced, though the torque efficiency is somewhat lowered. But I fail to see how the difference is so great as to warrant the statement that it would be better to increase the electromotive force in order to get the high current necessary to give the great torque, than to introduce the capacity to get that torque.

Then in reference to Figs. 1 and 2, as Prof. Goldsborough says, they are of tremendous importance, as showing how close our calculations can come to simple experimental results. At the same time I do not understand from the paper how many of the initial points in these various curves are necessary to assume before the method of calculation can be applied and the curves drawn. For if initial points must be assumed for all these curves, then that means simply that the form of the curve is shown by the equation, but it does not show that a predetermination of the characteristics of such a machine may be obtained. From a comparison of Figs. 3 and 9 it is apparent that only the initial value of the current curve is assumed in these various calculations; but it is not at all clear that it is not necessary to assume more than the initial values of the other curves as well, and the equations simply give the forms of the curves. Those are points of difficulty to me that I would be glad if Mr. Steinmetz would give me further light on.

MR. CHARLES P. STEINMETZ:—Referring first to the effect of capacity inserted in the secondary of an induction motor, on page 211 a curve is shown giving the effect of various values of capacity introduced into the secondary, without any additional resistance. From this curve it follows that the maximum value of apparent torque efficiency is reached at the maximum point of torque, that is at the point of complete resonance. But this maximum value of apparent torque efficiency is only 51 per cent. and on either side of this point the apparent torque efficiency falls off very rapidly. Looking now on the preceding page, the curve of apparent torque efficiency produced by various values of non-inductive resistance inserted into the induction motor secondary, we see that the value is beyond 80 per cent. over a very large range, and hardly anywhere, except very near the short-circuit point, drops below 80 per cent. This means that we can get a very large torque indeed by capacity, but at the expense of a still larger current, while by means of non-inductive resistance, and by raising the impressed voltage, we can get the same large torque with much less current. The best value of capacity is indeed the value giving perfect resonance, but even at that value the apparent torque efficiency is far below the values available by the use of non-inductive resistance.

With regard to the assumptions made in calculating the curves given in the paper, as stated therein, these curves are calculated from the values of impedance and admittance, both vector quantities. No further assumptions have been made, neither the initial point of the curve nor any other point. Obviously the initial point of the induction motor curve and of the induction generator curve are the same, since they are identical, representing the point of synchronism. These values of impedance and admittance from which the curves in the paper are calculated, may either be taken from tests made on the motor, or they are calculated beforehand in the same way as electrical data are generally calculated. The methods of calculation obviously belong in the field of electrical design and thus are outside of the scope of this paper. I may say, however, that these values, and therefrom the induction motor curves, can be calculated with perfect accuracy, and in fact have to be calculated very accurately, since obviously in larger motors it is generally not possible to change them after the motor has been built, and thus they have to be calculated correctly before the motor is built.

The formula for torque efficiency and apparent torque efficiency, $\frac{T}{P}$ and $\frac{T}{Q}$, is apparently the ratio of a torque over a power. However, in discussing torque of a motor, the same difficulty appears already which has led me to the introduction of the terms "torque efficiency" and "apparent torque efficiency." The value of torque in pounds at one foot radius has obviously no meaning whatever in regard to the electrical features of the motor, since a motor giving only half the torque of another motor but being designed for twice the speed of operation is obviously just as efficient regarding the torque produced by it, or inversely, a motor with a larger torque when designed for lower speed of operation may be inferior in starting efficiency to a motor of same capacity of lesser starting torque but higher running speed. That means torque, and more particularly starting torque can be compared only with reference to the speed for which the motor is designed. Since in the discussion of the paper no assumptions are made with reference to the number of poles and the frequency of the motor, that is to its speed, the torque in pounds at one foot radius cannot be calculated at all without these assumptions, but only the product of the torque into synchronous speed, which gives a direct criterion of the starting effect of the motor.

It is this value which I have introduced into the paper as *T* and spoken of as torque. It is the torque, but with a multiplier depending upon the construction of the individual motor and its frequency, and this multiplier is its synchronous speed. Thus *T* is in reality a power, and is given in watts and represents thus the power which the torque of the motor would develop at synchronous speed. Hence the name synchronous watts. This I believe will make the apparent discrepancy in the paper disappear.

The terms admittance and impedance introduced in the paper need some further explanation I conceive, but have been left without it, since they have been used in the same meaning by me before, in the theory of induction motors and of transformers.

Admittance, however, is usually spoken of as primary admittance and refers to the admittance of the primary circuit only, at open secondary circuit.

If an E. M. F. is impressed upon an induction motor or transformer, a magnetic flux is produced thereby which is partly interlinked with the primary and secondary, partly interlinked only with the primary circuit, or only with the secondary circuit. The former is the flux of mutual induction, the latter the flux of self-induction. The effect of these two magnetic fluxes is entirely different, and even opposite, and thus it is not well possible to investigate the action of an induction motor or transformer without separating these two fluxes or their corresponding E. M. F's. This separation is done in introducing two different quantities, the primary admittance and the impedance. The primary admittance refers to the flux of mutual induction only, that is, the magnetic flux produced by the primary and interlinked with the secondary; while the impedance, or more properly self-induction impedance, refers to the flux of self-induction, or flux interlinked with one circuit only.

Obviously the investigation could be carried through by using either only impedance or only admittance for both quantities, but here in the theory of the induction motor as of the transformer, it is more convenient to represent mutual induction by an admittance, and self-induction by an impedance.

The induction generator is a very important piece of apparatus, I believe. It is, however, somewhat restricted in its application, due to the necessity of having as load a circuit of leading current. But wherever the conditions are such that it can be used, as for operating synchronous motors or rotary converters, this type of machine has the great advantage of the absolute absence of continuous current exciting circuits, collector rings, or any other parts requiring attention. The voltage is generated in a stationary structure and the revolving part is a solid structure of iron and copper bars. Furthermore, as soon as the circuit is opened or short-circuited, the power is gone and the machine dead, so that you get here a type of alternator requiring no attention whatever. Besides you can run it at different speeds and still get the same frequency out of it.

There is another interesting feature noticeable when comparing the induction motor curves and the induction generator curves. The same machine as induction generator gives a considerably larger output electrically than as induction motor mechanically. In a future paper I shall dwell more particularly on the induction generator, and may mention here only that I have operated synchronous motors from an induction generator; and with the same voltage at the terminals of the induction generator, the mechanical output from the synchronous motor driven by the induction generator was larger than the maximum mechanical output which could be derived from the same induction machine as induction motor.

With regard to the agreement of tests with calculation, the agreement in induction motors is usually much closer than it is in continuous current machinery, and when you look into it you will see the reason for it. In continuous current machinery the magnetic circuit is worked at or beyond the point of the magnetic characteristic where saturation begins, and thus the M. M. F. consumed in the iron part of the magnetic circuit is a noticeable part of the whole M. M. F. Now it is not possible to predetermine the

c characteristics of the material of a machine with abso-
ıracy, since even a test made on a test piece broken from
ing of the very machine does not give correct results,
parts of the same casting differing from each other. In
n motors, however, and transformers the iron is necessarily
at a density below saturation, and thus the M. M. F. con-
the iron is very small. Hence the main source of dis-
between calculation and test in continuous current
s, does not exist in induction motors. Obviously occasion-
ıe discrepancy between test and calculation appears in
n motors also.

erm admittance essentially depends upon the length of
ap of the motor. The length of air-gap used in induction
s very small, and thus a variation in the air-gap due to
ction of mechanical construction is to a certain extent una-
. Occasionally I have found a discrepancy between the
d and observed value of impedance and especially its
omponent, the effective resistance, that observed by the
g larger than the ohmic resistance of the motor as derived
culation or measurement. In most cases of this nature
een able to locate the discrepancy in eddy currents pro-
mewhere in the mechanical structure, due to the prox-
iron or other solid metal, and by removing it have seen
curve drop back to the curves derived from calculation.
primary admittance of motors with very small air-gap
ly a certain variation must be allowed for the mechanical
ility of getting the length of a very small air-gap exactly
)therwise, however, you see that the problem of predeter-
of induction motors is really more favorable for accu-
tion than that of continuous current machines.

eve this is all which has come up in the discussion.

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ollowing paper on a "New Form of Induction Coil" was
sented by Prof. Elihu Thomson.

A paper presented at the 14th General Meeting of the American Institute of Electrical Engineers, Eliot, Me., July 26th, 1897.

A NEW FORM OF INDUCTION COIL.

BY ELIHU THOMSON.

The induction coil presently to be described, it is believed constitutes a new type employing the principle of a "substitute primary" or "secondary primary," which principle has been applied by me in a variety of ways.

The prime object of this coil is to permit the direct connection to circuits of considerable potential, for obtaining energy for the production of high potential discharges, like those of a Ruhmkorff coil for working Röntgen ray vacuum tubes, and for such like purposes. The object, also, was to avoid the employment of banks of lamps or storage batteries, and to limit the energy consumed to only that amount required to work the coil itself. Furthermore, no larger condensers than those ordinarily used with an induction coil of equal capacity are needed, and no air-blast, while the coil as a whole is still available as an ordinary Ruhmkorff without change in its structure or connections.

To illustrate the principle, reference is made to Fig. 1, where *p n* represent connections to mains at, say, 110 volts difference of potential; I I is an iron wire core around which are wound two coils, one over the other, either of which may, of course, be the primary. The inner coil P in the figure is made the primary, and is wound with many turns of comparatively fine wire. For 110 volts it may have some thousands of turns and be wound with a a wire safe for .5 to .75 ampere. The outside wire, s, may be coarse or fine. In the figure it is quite coarse and of relatively few turns, since it is assumed to give low potential and large current. The coil s is so proportioned as to be practically almost short-circuited at intervals by its load at B, which is three cells of storage battery in series, for example. The object is assumed to be that the batteries are charged by transference of energy from coil P to S at low potential in S. The coil S should have ample copper so as to lower its internal resistance as much as possible; the resistance of the cells B should be low; and the average voltage of discharge of S much superior to the counter E. M. F. of B. Two synchronously revolving break-pieces, E, F, which may, in fact, be combined into one, are used; E is for governing the intervals of passage of current in coil P and connection of condenser C across the break or interruption periodically made between one terminal of P by a brush G and a metallic segment on E occupying a considerable arc on its periphery. Brush H connects to main *n*. Back of the main segment on E is a small condenser segment in continuous connection with one side or foil of the condenser, and the other side is connected to the other terminal of P, or that

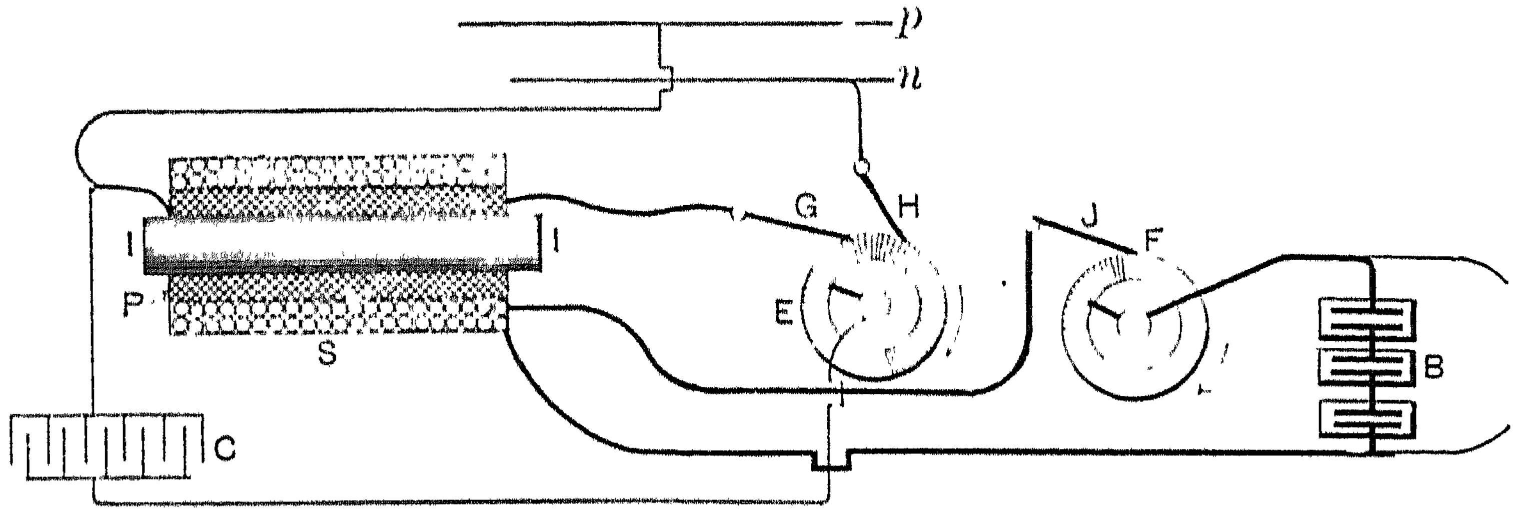

FIG. 1.

leading direct from line *p*. The contact maker and breaker F has a segment which is in continuous connection with one terminal of battery B to be charged, and which touches a stationary brush J, at or about the time of the break between brush G on the main segment of E. The battery B may have terminals by which it may furnish current while being charged.

Now let the break-wheels E and F be given rapid revolution, say, 10, 20 or 30 per second. The contact of brushes G and H with the main segment of E passes current for a certain considerable fraction of the revolution, at full line potential of 110 volts, through primary P. The current rises gradually during this period, and may at the end attain a value of one ampere, more or less. With slow revolution it would be limited by the resistance of P chiefly; but at rapid rates, the time constant of P acting as a self-induction, determines the ultimate value of current reaking. Upon the break of brush G with the main seg- touches the condenser segment which is thereby put he break, but the circuit of S is also closed by contact of t on F with brush J. The condenser receives only a small on account of the circuit of S having been closed. In e break at G with main segment of E would be nearly ss without the condenser C, but what slight self-induction iped out by the mutual induction of the currents in S and y easily taken care of.

nagnetizing of the core I I, or absorption of energy is by delivery of energy is by S acting as if nearly on a closed This condition, however, does not involve much waste gy if the ohmic resistance of the circuit of S be low enough. en, is a transfer of energy from one circuit to another e currents are direct currents in each circuit. To insure ng the case in S, the time of contact of segment on F with must be selected so as not to permit any reversal, *i. e.*, k of said segment with K must be timed to be made on ation of the first impulse or discharge from S. To do this eter, responding to direct currents only, placed in the bat- uit, or in the leads from S, will indicate a maximum rrent when the segment F is of proper extent, and less her conditions.

the principles of the above apparatus in mind, it is easy stand the action of my new form of induction coil, which described, briefly, as follows. The iron core I, Fig. 2, of ction coil, is wound with the ordinary coarse primary coil inals provided therefor. Then a coil of intermediate etween the inner primary and the outer secondary, is It is to be capable of being connected across a circuit of s as with coil P, Fig. 1. This coil is the true primary or upplying coil, but for convenience and saving of wire I connect it in as the under portion of the real secondary It thus becomes useful as a part of the secondary itself ng several thousand turns, adds a considerable fraction tal potential of the secondary. The secondary is, as quite fine wire of many thousands of turns, well insu- oughout.

2, the coarse coil is marked S P, and the intermediate while that outside is marked S. The functions of the and P S are to act as secondaries and primaries alternately.

This is, in fact, an essential function of S P, but is only incidental to coil P S, having been connected into the secondary circuit S, whose terminals are at *t t*. The break-wheels E F are like those of Fig. 1, except that in F there is a much shorter main segment and a condenser segment following, as in E. There is no battery in the circuit of S P, but it is put on dead short-circuit at intervals, just at the time P S is broken. Coil P S receives current from line at *p n*, at 100 to 200 volts, or more. On the break of this circuit at brush G the ampere turns, so to speak, are shifted suddenly into circuit of S P, closed on itself by J F. The consequence is that even at slow breaks no spark occurs at the rupture of G E. As soon as the current has been fully established in S P on short-circuit, and after brush Q has got entirely away from all metallic connections on E, the main segment of F breaks the circuit of S P which is conveying a very heavy current at low potential. The condenser C is put instantly across the break, and the spark flies between terminals *t t*. In this way a coil of the size of a six inch Ruhmkorff, gives a torrent of six inch sparks with an average current from a 110-volt line of about one-half an ampere. A simple motor or clock-work may be used to drive the break-wheels E F which are made of fair diameter to insure accuracy in operation. The best results are only to be obtained when the proportioning of the parts is carefully done, and with a knowledge of the result to be obtained.

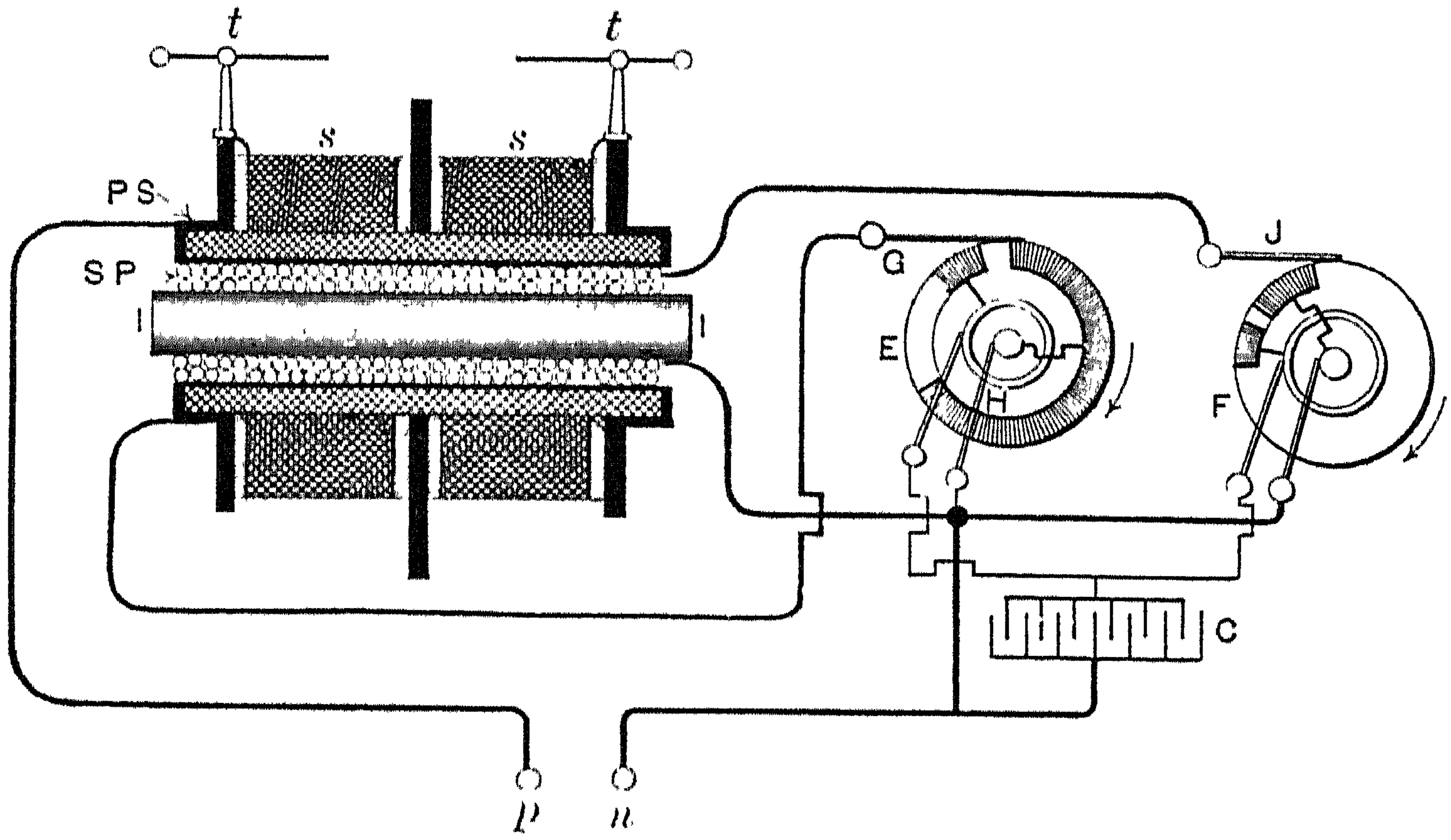

FIG. 2.

The discharges are indistinguishable from those of a similar Ruhmkorff. In fact, the coil described might be used with the same condenser C as an ordinary Ruhmkorff coil energized by batteries. In this case the terminals of the coil section P S are disconnected, brush J lifted, and battery inserted between brush G and terminal of S P, which goes to J in Fig. 2. The break-wheel, E or F, when run with low potentials may be immersed in water in the usual way to facilitate sharp breaks, but the apparatus has been very successfully run, at full output, dry, or a little heavy oil on the break suffices. Also, the flux of current in S P may be made by a magnet to break its own circuit under water when the current has risen to a predetermined amount. In other words, it may be provided with the usual automatic break, damped or adjusted not to get into tremulous vibration. It will be seen from the above description that a new way of energizing an induction coil, or other transforming apparatus, has been embodied and that it consists in the rapid substitution of secondary and primary functions in the coil S P.

DISCUSSION.

DR. A. E. KENNELLY:—I think that this is an ingenious device and by giving my interpretation of its use, I may, perhaps, not only show some of its advantages over other forms, but also elicit Prof. Thomson's criticisms, in case I fail to describe the apparatus adequately.

When you excite the primary winding of an induction coil through an interrupter or revolving contact-breaker from a 110-volt circuit, it is difficult to break the circuit at the interrupter promptly and to avoid a vicious spark. If, however, you use a coarse-wire primary winding and a storage battery or low-tension source of excitation, the sparks and breaks are much less troublesome.

Prof. Thomson says: I want to use a 110-volt primary exciting circuit for convenience, and yet obviate the difficulty of breaking the arc at the interrupter. I do this by short-circuiting an intermediate coarse-wire coil just before each interruption, and I thus start a powerful low-tension current in the intermediate coil with the energy which would give rise to the primary spark. Now the primary current can be interrupted without difficulty. As soon as it is safely broken, I break the powerful current in the intermediate circuit, just as though it were obtained from a low-tension source and obtain all the effects in the secondary circuit due to a low-tension excitation.

PROF. THOMSON:—If there are no further remarks I would say that Dr. Kennelly is quite right. He has put the case exactly as I would have had it put. The use of 110 volts in working the induction coil has required hitherto a very high-speed break, and only moderate currents flowing in the coils, in which case there is a tendency to get in the secondary, alternating discharges or discharges very similar to high-frequency discharges, positive and negative. But in this case the tendency is to a unidirectional discharge as in the ordinary Ruhmkorff. At the same time I should have said that the working of the break-piece in this case is substantially without spark, and can be worked without any such devices as air-blast and without working under water. It can even be oiled while it is in operation and the effect is perfect. The objection to the arrangement of course is, that it involves the use of a revolving break-piece to put the circuits through these various paces; that is the connections must be made and broken in just a certain order and with just a certain relation to each other, that has to be determined beforehand and settled once for all. It is not of course as simple as a simple hammer break which opens a contact, but it is certainly more simple than a revolving break which has to have an air-blast or arrangement for continuously putting out the spark. Even then one gets a good deal of fire at the contacts.

[Recess.]

Monday, July 26th, 1897.

Evening Session.

The formal opening exercises of the 14th General Meeting re held in the "Eirenion" at 8.15 p. m. where the Institute was ven a hearty welcome by Miss Sarah J. Farmer, and her re- esentative, Dr. George F. Barker in the following words:—

Miss Farmer:—Mr. President, members of the Institute and lies. The loving-kindness which you have shown in coming us, participating in our conference and assisting in our loan hibit touches me deeply. I feel more than I can express to u, and I have asked my father's friend who loved him, and om my father loved, Dr. George F. Barker of the University Pennsylvania to speak the greetings for me to-night.

Dr. Barker:—I have greatly enjoyed, ladies and gentlemen, the mosphere of Greenacre in the few hours that I have spent here, t there seems to me to be in this atmosphere an element that is culiar. I have no physical reason for believing that ideas are xed in the atmosphere as material substances are, but I imagine ey are. At all events I find myself to-night inclined to think at there is a peculiar atmosphere here which I have not seen t down in the programme. I feel as though I had been pnotized, and I am not sure but that it is so, for the hypnotists l us that the power of a stronger mind over a weaker, forces e weaker to do whatsoever the stronger commands. Those of u who have been here these past weeks, and those of you o have been here during the past years know well what I ean. A mind which can organize such an institution as you find re, a mind which can bring all these people together, full ideas to give and to receive from each other, is a stronger nd, and I am delighted myself to be put hypnotically under e influence of such a stronger mind as I am sure we all agree at Miss Farmer is. I justify my remarks then by simply saying at I am speaking for her and when I offer words of welcome I it under hypnotic influence.

We all have some ideas about a future state, about immortality; t howsoever we differ in regard to what that actually means, all agree in this, that in some respects the immortality of this e is quite as important and quite as powerful as the immortality the future life.

He who does for his generation that which is worthy of being ne; he who improves the condition of his fellow men; he who in- nts for their benefit; he who discovers that they may live better d be better, is sure of a present immortality. Now to what am sked to welcome the American Institute of Electrical gineers? To this atmosphere, an atmosphere sacred to the emory of Moses G. Farmer. It might be to this beautiful ace, it might be to all the attractions which are here, it might be to all the delightful people whom we are to meet, but those are as nothing in comparison with the magnificent atmosphere of the doings of Mr. Farmer, which they will find here and which they are to breathe. We can breathe in an inspiration as we can the atmosphere, and none of us who have been here and paid our homage to the memory of that great man will fail to go away from here feeling that the inspiration of a great name has been more to us than all else which is here besides.

Miss Farmer has been kind enough to say that she has asked me to speak to you to-night because I knew her father so well and admired him so much. I feel as though I were in a special sense in his presence, when I see here upon this platform these two delightful portraits. I am especially glad that Mrs. Farmer's portrait has been put here too, for I know so well the service which she rendered him in all the work which he did, and I feel that among all the blessings which God has given to man there is none better than a faithful and true wife.

My first meeting with Mr. Farmer was many years ago, more perhaps than some of us who are getting along in years like to recall. There is one point in which our science at the present day seems to me to be quite deficient. There still is maintained an alliance in the case of two of the sciences, between which I am sure a divorce ought to be decreed, and that is the alliance between the sciences of astronomy and physiology. I see no reason physiologically why we should get older in proportion to the number of times that the earth goes around the sun. It was in 1852 while I was an apprentice in a philosophical instrument store in Boston that I first met Moses G. Farmer. I was sent to carry some apparatus which he had bought. I went to the fire alarm room in Court Square with this apparatus, and he at once received me very kindly and asked me if I knew what he was about. Well, I had a general idea, but knew nothing in detail; and he, busy as he was, took the opportunity of explaining to me the system of fire alarm telegraph which he was then arranging in Boston. We became firm friends. He called me Fred to the day of his death, and that is one of my most cherished memories. We all understand what this fire alarm system was, so that I will speak of it only in the personal connection. You will remember the system was designed to call out the districts on the alarm bells of the city, this information being sent to the central office by the simple operation of turning a crank on the axis of which there were projections, these projections indicating by a letter or number where the fire was. It was here that he began his work, and it was here that he carried it through. Moreover it was during the work that he did in that fire alarm office that he made use of a magneto-electric machine driven by water power for the purpose of sending out the alarm. After that he moved his laboratory to Sudbury Street, and being in Boston about that time in connection with the Harvard Medical School, I used to spend a great deal of time in this laboratory. It was there that he developed the system of incandescent lighting which has been so frequently referred to. I remember this apparatus very well. That tangent galvanometer which we see in the loan exhibit was one of the pieces of apparatus which he there employed. I went in there one day and he said, "look here." He took a little piece of platinum plate and cut a strip from it. He measured very carefully with a micrometer the length, breadth and thickness of the strip. Then by means of a formula he had worked out, he calculated the amount of current it was necessary to send through that strip in order to bring it to its melting point. He put the strip in circuit, turned the current on, and increased it until the point was reached on the tangent galvanometer giving that current, and the platinum became incandescent. He then said I will show you the correctness of my formula. He increased the current one degree and the platinum melted. It was in connection with this arrangement that he devised the movable rheostat by which if the current varied, the rheostat took care of it and threw in resistance so that the platinum lamp should not receive too much current; a clear anticipation of the first devices made use of when the platinum lamps came into more extensive use. I have in my possession too, some of the bars of a thermo-battery which he made at that time, the metals being an alloy of antimony and zinc combined with a copper strip. In regard to the dynamo machine which has been referred to, we all remember that the principle is that of self-excitation. You cannot put a piece of iron in any position whatever, without its being to some extent a magnet. The instruments which had been used for generating currents hitherto, utilized permanent steel magnets. His idea was that any piece of iron is more or less a magnet, and if you happen to put that piece of iron in the direction of the magnetic needle, it is more strongly a magnet. He said there is magnetism enough in every piece of iron for us to use it. Suppose we move a coil of wire near that bar, that coil of wire in consequence of that motion has a small current induced in it. Suppose I send that current around the bar; that will magnetize the bar and that will then generate more current, and so on until the maximum is reached. There are three methods by which this was done, and Mr. Farmer's, as Mr. Wilde has told us, and as the Proceedings of the Philosophical Society of Manchester clearly proved, antedates both Wheatstone's and Siemens'. So all the time we see that this man was working quietly, piling up note-book after note-book and never publishing, though he was repeatedly urged to publish. There is a line sometimes drawn between those who discover, and those who apply the discoveries of others to useful purposes; between the man of science, so-called, and the inventor. Now to a very large extent Mr. Farmer's utilizations were Mr. Farmer's discoveries. I remember very well in 1863 there was a wonderful exhibition for that time of an electric light upon the evening of the 4th of July on the Boston State House. Prof. William B. Rogers had charge of the exhibition, and a very large Bunsen battery was placed in the dome, and wires were led up, and this light was shown at the same time with the fireworks on Boston Common. There was somebody else up there beside Prof. Rogers and his assistants, and that man was Mr. Farmer. They wanted to make a display, they wanted to show an electric light larger than any that had been seen up to that time. Mr. Farmer had no such idea. He wanted to do what had not been done in the world before and what has not been done, possibly with one exception, since. He wanted to determine how much energy, how many horse-power it required to produce that light, and out of the data which he obtained in those experiments in the dome of the Boston State House, on that night of the 4th of July, 1863, came the mechanical equivalent of light. He then proved that to support the light (not the heat, but the light) of one candle required the expenditure of 13.1 foot pounds per minute. Some time after that, Prof. Thomsen of Copenhagen, undertook from similar data to get this result, and the two results were very closely accordant. Now this fact shows two things, and those are the only two things I want to say; first, that most of the matter that is in Mr. Farmer's note-books is matter which was new to science at that time. He was therefore a great scientific discoverer. I urged him and others urged him to publish, but that innate modesty of his prevented him from doing so, and consequently many of those things which were in his note-books are now known in the form of practical outcome obtained by others. I maintain that those note-books contain discoveries that should be credited to him. Secondly, he was also a great inventor, and the inventions which he made, you have evidence of in the fragmentary exhibit here, which, while it is a very fine exhibit, is far short of what it might have been had we been able to collect all Mr. Farmer's inventions and put them over there. Now, may I not say, in view of this hasty résumé that I have given, that this atmosphere is an atmosphere to which it is well worth while to invite the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, and may I not say that the atmosphere in which Mr. Farmer lived and worked, is an atmosphere where the members of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS cannot but receive an inspiration and an impulse. If I am right in this conclusion, then I have to return into my hypnotic state and to extend, in behalf of Miss Farmer and all the friends here who are conducting this splendid enterprise —to extend to my friend the President, Dr. Crocker, and through him to the members of the INSTITUTE, a most hearty welcome to this hallowed spot. [Applause.]

PROF. CROCKER:—Mr. Chairman, ladies and gentlemen—It is a matter of great satisfaction that the INSTITUTE is able to do some-

honor to our late honorary member, Moses G. Farmer. He
esented what I consider to be the idea lelectrical engineer, be-
e he combined the two branches of that subject, the theoretical
the practical. Dr. Barker has just pointed out that most of
ork was done on the borderland between what we call pure
ics and applied electricity. It would seem as if this com-
ion of the two was most perfect and that either alone, with-
he other, is incomplete. The electrical engineer could not
pure scientist, and while the latter might be a member of
ody he would not represent the title in the most perfect
ner. But in Prof. Farmer we have an ideal example of that
balanced combination of pure science and useful application.
efore we can do full homage to him, and the INSTITUTE will
ys cherish, I feel sure, not only his name but also it will be
ted by the example which he set to its members.

taking up the subject of the evening, "The Precision of
trical Engineering;" it occurred to me as Dr. Barker was
ing, that Prof. Farmer's mind had that very exactness which
going to attempt to bring out. On several occasions his
ds have spoken of the exact measurements which Prof.
er employed in his work, and Dr. Barker has just cited a
in which Prof. Farmer was able to predict the exact amount
rrent required to fuse a certain piece of platinum. It is
very precision, that very power of prediction, that I claim
ur profession, and it seems therefore especially appropriate
I should now attempt to set forth this accuracy which char-
ized Prof. Farmer's work. The subject is obviously not a
lar one. Nevertheless it is, I think, of general interest and
opular mind, as well as the scientific, is never tired of hear-
f the wonderful achievements of electricity. It is a fascinat-
ubject which never seems to lose its charm, and therefore
e that some of the points will interest those present who are
electricians, although this address was of course prepared
the professional point of view. I may also state that I have
een able to do justice to the subject or to the occasion, owing
or health during the last few months; but this theme is
werful in itself that it simply requires to be started and it
carry itself along.

esident Crocker then gave his address as follows:

Inaugural Address of the President, at the 14th General Meeting of the American Instisute of Electrical Engineers, Eliot, Me., July 26th, 1897.

THE PRECISION OF ELECTRICAL ENGINEERING.

BY FRANCIS B. CROCKER.

There still exists quite a general idea that electricity is so imperfectly understood that its laws and actions are little more than matters of chance or guesswork. The experience of the electrical engineer is supposed to consist of a series of surprises and shocks to his mind as well as to his body. This notion is not confined to the ignorant, but is believed by many educated persons, even including our brother civil and mechanical engineers; indeed, some members of our own profession hear this opinion expressed so often that they partly accept it as true, or at least they have no ready arguments with which to refute it.

The existence of this popular error concerning electricity is perfectly natural, and arises from the novelty of the subject and the fact that its development has been so great and so rapid that no one but a few specialists has been able to keep pace with it.

The subtlety, extreme rapidity of action, and the astonishing achievements of this modern agency make it appear most mysterious and occult in comparison with the ordinary forms of energy, such as heat and mechanical power. Possessing such transcendental powers, it is looked upon as something not only unknown, but unknowable, an irresponsible power for great good, or great evil. This idea has sometimes been the cause of actual harm to the progress of electrical engineering. The profession has been considered to be hardly legitimate, those who practised it being regarded as either wizards or charlatans, or a combination of the two. During the present year, the president of a large steam railroad system, on which electric propulsion is being tried, publicly expressed his opinion that electrical engineers know little or nothing of their subject. In legal decisions in this country and abroad, judges have stated that electricity was so vaguely understood, that testimony concerning it was of no practical value.

It has also been held by many courts, that electricity being intangible, has no real existence, so that the tapping of current from the wires could hardly be considered as a theft, except in an imaginary sort of a way. The production of electrical energy in central stations has been decided by metaphysically inclined judges to be a totally different kind of business from the manufacture of gas. In point of fact, the differences are all in favor of the practical character of electricity. More useful operations can be performed by it; it can be more easily transmitted and distributed; the percentage of leakage is less, and its measurement is far more convenient and accurate.

The idea that "no one knows what electricity is, therefore we know practically nothing about it," is often expressed by those who want to excuse their own ignorance of the subject. They are glad to think that they are no more worse off in this respect than the rest of the world. Their deduction is quite natural, but is absolutely fallacious. While we must admit that we do not know the real nature of electricity, the same limitation of knowledge applies to all other fundamental facts. Gravitation is the most familiar of natural phenomena, yet we have no conception whatever of what it actually is. Our theories and mental pictures of the nature of electricity are much more definite than those concerning gravitation. In regard to the latter, little progress has been made since the time of Newton, while electrical knowledge has advanced and is now advancing with giant strides. There is every reason to believe that we shall "know what electricity is" and be able to explain the inherent mechanism by which electrical actions take place, before we understand how and why a stone is drawn to the earth. What we do know, however, are the laws of both electricity and gravitation, as well as the results that they produce, and it is very doubtful if our ability to control, measure and utilize these agencies would be improved even if we understood their exact nature. The laws and applications of hydraulics would be just as definite and successful even though the fact were not known, that water is composed of two atoms of hydrogen and one of oxygen. It is possible that methods of generating electricity may be advanced when its real character is discovered, but it is not likely that this knowledge will greatly affect the methods of handling and using it.

The popular ignorance and doubt concerning electricity is rapidly disappearing in consequence of the remarkable results accomplished by it during the last ten or fifteen years, but it will not be out of place, I think, to consider at this time the remarkable exactness which electrical engineering has reached. A discussion of this question may serve to inform laymen who are not familiar with the facts, and may also be a matter of interest and satisfaction to ourselves. This profession has only very recently gained for itself a position of independence and equality among the branches of engineering, but it can now fairly claim to be an example for the others to follow, not only in the magnitude and rapidity of its results, but also in the exactness and certainty of its methods. Let us consider what are the principal facts upon which this strong claim it based.

The names connected with electrical science:—Gilbert, Franklin, Faraday, Ampere, Maxwell, Henry, Helmholtz, Kelvin, and a long list of other distinguished electricians, are not men whose ideas are vague or incorrect. Indeed, it is a significant fact that the ablest and most profound scientific men have been attracted by, and have performed some of their best work in the study of electricity.

The rapid progress of electrical science and its applications is an absolute proof of sure and exact knowledge. Uncertainty would necessarily cause delay, and error would involve repeated trials before success could be reached. The fact that the difficult arts of long-distance transmission of power, and electric traction have been developed to their present state of importance and success in about ten years, shows conclusively that electrical theories and designs agree very closely with the actual facts.

The great results accomplished by electrical engineering is probably its strongest claim. Many of these are so unique and astonishing that we still regard them with wonder even after we have become familiar with them. Among the most striking of these examples are the locating of faults on submarine cables, telephoning a thousand miles or more, transmitting power over one hundred miles, sending simultaneously a number of messages on the same wire, utilizing the power of Niagara, and producing the Röntgen ray. These and hundreds of other wonderful feats are not accomplished by chance, or by groping in the dark.

The close relationship between pure and applied electrical science is still another proof of the exactness and truth of both. If knowledge were complete, theory and practice would become identical. The agreement between theoretical and practical electricity is largely due to the small losses which occur in electrical apparatus and processes. Even quantities which correspond to friction in mechanics, such as electrical resistance and magnetic hysteresis, are capable of exact calculation. It is only the purely non-electrical factors, such as the friction of bearings and air resistance, that are uncertain in designing electrical machinery. The almost infinite rapidity of electrical action makes the time element so small that it can nearly always be neglected. This greatly simplifies calculations and renders their results more accurate. The fact that there is only one kind or quality of electricity also gives definiteness to our ideas and calculations. With coal we must know its quality, including both its physical and chemical properties, in order to make even approximate calculations concerning it. In the case of steam, pressure and volume are not sufficient data; the amount of moisture or superheating must also be known. The most accurate methods of the physicist are not any too good for, nor beyond the reach of the electrical engineer, and they are often employed by him. A notable example of this is Lord Kelvin's work in connection with laying the Atlantic cable, which was undertaken at about the same time that he began to publish his essays on the vortex theory of matter. When Werner Siemens first built his self-exciting dynamos, he also constructed the sensitive galvanometers, used in the researches of his friend Helmholtz. It was Siemens, the electrical engineer, who gave his money and influence to the Reichsanstalt, an institution where the most accurate physical work is now being carried on.

A historical example of the agreement between electrical theory and fact is the brilliant work of Ampere, who gave to the world a beautiful and complete theory of electro-magnetism within a few days after he heard of its discovery by Oersted. The work of Maxwell is another great example of the power of the intellect to deal with electrical problems.

Hertz said, in regard to Maxwell's electro-magnetic theory of light: "It is impossible to study this wonderful theory without feeling as if the mathematical equations had an independent life and an intelligence of their own; as if they were wiser than ourselves, indeed, wiser than their discoverer; as if they gave forth more than he had put into them. And this is not altogether impossible; it may happen when the equations prove to be more correct than their discoverer could with certainty have known."

It can hardly be admitted that there is anything in Maxwell's equations that he did not put into them, but the remarkable experimental corroboration of Maxwell's theories many years after they were evolved, shows that from a few fundamental truths almost the whole theory of electricity may be deduced.

This power to solve problems successfully by *a priori* reasoning demonstrates the perfection of electrical science. We can arrive at the facts by reasoning out what they ought to be; hence we may say that electrical science is ideal. In other branches of applied science, as for example in civil engineering, the corrections, factors of safety and other allowances are often much greater than the original quantity itself. In such cases it is obviously impossible to go very far from an experimental fact, by any process of reasoning. The errors would immediately become so magnified that the truth would be greatly distorted or lost entirely.

To take a concrete example, the losses in transforming electrical energy are only two or three per cent., and if an error of ten per cent. is made in calculating these losses, the actual error is only two- or three-tenths of one per cent. It would, therefore, be possible to design a system in which electrical energy was transformed many times, and yet the final error would only be one or two per cent. If, on the other hand, the losses in mechanical engineering are ten or twenty per cent., or even fifty per cent., as is often the case, an error of ten per cent. in calculating these quantities would soon become multiplied to a large figure.

Exactness in electrical units and terms is another strong point of electrical engineering, because definiteness in terms and ideas go hand in hand. The system of electrical units is complete and scientific, being based directly upon the C. G. S. system, and is the only example of a set of units which are universally adopted. The metric system is not in use in the United States, Great Britain and her possessions and many other countries, but the same electrical units are accepted by all nations. This avoids the great confusion which arises from the use of several different units for the same thing, as is the case in steam engineering, in which at least four different heat units are commonly employed.

In electrical engineering the distinction between the various quantities are usually more clearly understood, as for example the difference between force, work and power. In other branches these quantities were often confused, and the fact that mistakes of this kind are not more often made at present, is largely due to the influence of electrical engineering in the accurate use of terms. The useful word torque has been introduced through electrical engineering although it is a purely mechanical quantity. The adoption of such terms as impedance and reactance gives a nicety of expression which is rarely found in other applied sciences.

The facility and accuracy of electrical measurements contributes greatly to the precision of electrical engineering. Volts and amperes can be easily, quickly and accurately measured by means of convenient portable instruments. The product of these volts and amperes gives the watts or power which is the most important quantity.

If desired, a single instrument—the wattmeter—can be used to combine the two quantities. Electrical resistance can also be measured easily and quickly, and with still greater accuracy. Even the less common electrical quantities, such as capacity and inductance, can be measured without much difficulty and with reasonable exactness. The magnetic quantities are also quite easily and correctly determined. As already stated, the most doubtful factors in electrical engineering are the mechanical ones.

The enormous range in electrical engineering is still another proof of its precision. The same laws and principles which apply to the almost infinitesimal galvanometer current are equally applicable to the current from an electric light station. The former may be only a hundred billionth of an ampere and the latter reaches ten thousand amperes, which is a thousand million million (10^{15}) times greater.

An even greater ratio than this represents the range of resistance measurements. In the case of large copper bars, a determintaion to within .000001 ohm is often required, and for insulation testing 10,000 megohms is not an unusually high figure. This gives a range of measurement of ten thousand million million (10^{16}).

An electrical instrument, the bolometer of Professor Langley, is used to measure the heat received from the fixed stars, and electricity is also the agent selected when 100,000 horse-power are to be distributed from Niagara. Instead of saying that electricity is selected for these extreme uses, it would be more correct to state that it must be employed, just as it is the only means of transmitting speech a thousand miles, or performing the many other miracles of which it alone is capable.

The directness and high efficiency with which electrical energy can be converted into other forms is another fact which gives exactness to our work. It can be transformed into heat, light, magnetic, mechanical or chemical energy, by the simplest means, and conversely, the latter forms, with the possible exception of light, can be readily changed into electrical energy. In most cases the conversion is almost perfect, the efficiency of an electric motor or dynamo being usually over 90 per cent. and often 93 or 94 per cent. The chemical energy in a storage battery represents nearly 90 per cent. of the watt-hours applied to it, assuming the losses in charging and discharging to be about equal. The storage of magnetic energy may be effected at an even higher efficiency of 97 or 98 per cent. and the conversion of electrical energy into heat is complete, the efficiency of an electric stove actually reaching the ideal figure of 100 per cent. The production of light cannot be accomplished so economically, nevertheless the arc lamp has a far higher efficiency than any other artificial source of light, although it is usually stated to be only 8 or 10 per cent. It is also more than probable that the long-sought-for high efficiency lamp will be an electric one when it is finally invented. This facility and economy of transformation puts electricity directly in touch with the other sciences and their applications, avoiding the chances for error which round-about processes necessarily involve. None of the other forms of energy possesses anything like the same convertibility. The one serious difficulty in connection with electricity is the fact that its generation requires a boiler, engine and dynamo, bringing in heat and mechanical power as steps in the process. If this complication could be avoided, and electrical energy produced directly from the chemical energy of the coal, the only limitation would be removed. This has already been done in an experimental way, and by the substitution of water-power for steam, one piece of apparatus and one form of energy are eliminated, but the complete independence of electrical engineering and the realization of all of its possibilities will be secured when the direct conversion of fuel energy into electrical energy is accomplished practically.

It has been shown that there are no less than eight substantial grounds upon which the precision of electrical engineering is based. The consideration of these has incidentally brought out several concrete examples, but it will be well to cite a few other special instances which demonstrate electrical exactness.

The one which first claims our attention not only on account of its historical precedence, but also from its wonder-compelling results, is the locating of faults in ocean cables. In this connection I quote from information kindly furnished me by one of the vice-presidents of the INSTITUTE, Dr. A. E. Kennelly, who has had a long and successful experience in this branch of the profession. He states that "In the case of cable coiled in a tank and which has been taken into the tank over a measuring drum without being subjected to any considerable tension, the precision with which a fault in the gutta percha can be located is sometimes very considerable. I have known one or two cases in which a fault has occured in a length of say thirty miles of cable immersed in water and maintained at practically one temperature in the tank, and in which, by means of the Varley loop test repeated many times and under various conditions to eliminate constant errors, the electrical position of the fault has been determined to within a probable error, representing about twenty feet of length. On turning the cable over from one tank to another by a seven foot drum on which the cable makes three turns, and cutting the cable when the computed distance has been run over, the fault has been found on the drum, that is, in the sixty feet or so of cable then lying on the drum."

"As regards the location of faults in submarine cables on the ocean bed, the precision depends upon a variety of circumstances, and in general is necessarily much lower than in the case of a cable coiled in a tank. The average error in practice, or the difference between the true electrical and computed positions, is perhaps about fifteen ohms, or about one mile and a half of cable having the common resistance of ten ohms per mile. Under favorable circumstances a complete break in a cable developing a fair extent of surface exposure to the sea water at the end of the copper conductor, the electrical position can be determined within five ohms in a total conductor resistance of 1,000 ohms. In the case of a fault in the insulator, sufficiently serious to interfere with signalling, specially favorable cases will occur in which the electrical position of the fault can be determined to within one ohm when a loop test is obtainable and when the total conductor resistance of the loop does not exceed 3,000 ohms." "I have known a case of total loss of continuity in the conductor, accompanied by perfect insulation. It occurred in lifting a cable for repairs and was within half a mile of the ship. A measurement of electrostatic capacity enabled the distance to be determined within a few yards." Other cases are given by Dr. Kennelly, and many may be found in various works and journals, but these are sufficient to show the astonishing results that are possible, as well as those that are obtained in regular practice.

The methods employed in locating faults in underground conductors are quite similar to those used for submarine cables, but the results are less striking and important. Mr. William Maver, Jr., who is an authority on this subject, cites a case in which the calculated position of a fault was 2,343 feet from the testing end of an underground cable 4,200 feet long. The defect was found at the exact point indicated. The alternative would have been the tearing up of the street and cutting through a heavy iron pipe until the fault was found, as the conduit was not provided with manholes. One way to locate a ground connection, which illustrates the simplicity and certainty of electrical testing, consists in sending a current through the conductor to the ground through the fault in the insulation. A compass carried along over the cable will indicate by its deflection or non-deflection when the fault is reached. The facility of overcoming distances and obstacles impassable to other agencies is characteristic of electricity and magnetism.

The writer has had occasion to test the resistance and position of faults ("grounds") on a very large system of underground conductors for electric lighting. Although the problem was complicated by the fact that it was a three-wire system which extended several miles, it was found possible to determine the insulation resistance of each of the three conductors. The position of a "ground" is shown by the potential difference between the conductor and the earth, being a minimum at that point. For example, if a ground connection exists on the positive wire and a considerable current flows through it into the earth, the potential of the earth at that point will be raised above its normal value. The potential difference existing between the wire and the earth is actually less near the ground connection. This may be measured from the station by using the "pressure wires" ordinarily laid with the feeders, and special wires which connect to the ground at various points of the system.

The paper on "The Alternating Current Induction Motor," presented by Vice-President Charles P. Steinmetz at this meeting of the INSTITUTE, affords an excellent example of the marvelous precision of electrical engineering. In Figs. 1 and 2, two curves are shown which give the efficiency, speed, power-factor and other characteristics of a three-phase induction motor under various conditions. These curves were all predetermined by calculation. In the same figures the results obtained by actual test are also marked by small crosses. The agreement in all cases is so close that curves plotted from the actual results of tests would practically coincide with those predicted by calculation. This is all the more remarkable when it is remembered that the three-phase motor is one of the newest of electrical machines, and is a difficult problem from a theoretical standpoint. It has long been possible in designing direct current machinery to predetermine the results with almost as great accuracy as that shown in the curves of Mr. Steinmetz, but of course that is a much older problem. Nevertheless, the predetermination of results in direct current machinery is fully as difficult as in the case of alternating current apparatus, because permeability is the most doubtful factor in such calculations and is especially so at the high flux densities used in the former. It is to be observed, however, that any error in the permeability data can be corrected by increasing or decreasing the ampere-turns on the field magnet. This is easily accomplished by providing five or ten per cent. greater M. M. F. than the calculations require, which may be reduced, if necessary, by the introduction of resistance. Since the energy used for the field is a very small percentage of the total amount, it may be considerably varied without materially affecting the other factors in the machine. Sparking at the commutator brushes is an additional and by no means simple question which confronts the designer of direct current apparatus. I remember, however, being informed by Mr. Gano S. Dunn several years ago that he had found by experience in many cases that the efficiency of a direct current dynamo or motor can be predetermined from the drawings before the machine is built, within a fraction of one per cent.; in fact, he relied more upon his calculations than upon an actual test of the completed machine, even when performed by skilled men. In one case the calculated efficiency was 93 per cent. and the result obtained by test was 92.7 per cent., and in another case the total flux was found to be 1.38

per cent. greater than the computed value. This agreement is somewhat closer than is found in every day practice, but is not accidental and can usually be approximated by careful work.

We naturally suppose ourselves to be familiar with mechanical energy and heat; but as soon as we convert these well known forms of energy into that extremely subtle and mysterious agent —electricity—it immediately becomes far more definite and convenient to control, measure, transmit and utilize. In becoming intangible, it forthwith acts as the most reliable and matter-of-fact tool in the hands of those familiar with it. For example, the quickest, neatest and most exact method of making a test of mechanical friction, or the power required in any given case is by the use of an electric motor. In this way, for example, we can determine the friction of different bearings or lubricating oils under various conditions of pressure and speed, or the power consumed by fans, pumps and other machines.

Quite a striking example of the possibilities of electrical measurement is the determination of the E. M. F. of a dynamo machine without running it, which I saw successfully carried out more than ten years ago. All that is necessary is to measure the torque exerted by the machine with a given current in its armature. This may be accomplished by simply clamping a stick of wood to the pulley and weighing the pull at a given radius by means of a spring balance. If the same machine were run as a dynamo and had no losses, it follows that

$$\frac{EI}{746} = \frac{2\pi r S P}{33{,}000},$$

whence

$$E = \frac{r S P}{7.04\, I},$$

in which r is the radius at which the pull is measured, S is the speed in revolutions per minute at which the dynamo is to be run, P is the pull in pounds at the given radius and I is the current in amperes. The field strength is supposed to remain the same. This method is correct whatever the efficiency of the machine may be. The electrical and magnetic losses due to the $I^2 R$ effect in armature, field current, eddy currents and hysteresis do not enter this problem. Even the mechanical losses arising from friction of bearings, brushes, etc., may be eliminated by measuring the pull plus the friction and then minus the friction, the actual pull being one-half the sum of these two results. The effect of friction may also be gotten rid of by tapping t when the measurement is made. It certainly strikes one as that E. M. F., which depends upon cutting lines of force, determined while the machine is standing still.

In electro-chemistry and electro-metallurgy quantitati tions are particularly precise. The ampere being define current which deposits .001118 grammes of silver per seco weight of any other substance is by Faraday's laws propo simply to its chemical equivalent. This definition elimina error in passing from the electrical to the chemical data, versa. The volt is also defined electro-chemically in term E. M. F. of a Clark cell.

The author presented before the INSTITUTE, in May, paper on "The Possibilities and Limitations of Chemical ators of Electricity,"[1] in which the weights of materials, and other data were given for various voltaic combinations. of the figures were obtained by experiment and some by c tion. The paper also gives the E. M. F. produced by combi of thirteen of the most important metals with chlorine, br and iodine, respectively. The average difference betwe calculated and tested values was less than one-tenth of Even this small error is practically eliminated when the are corrected by the equation of Helmholtz, that is, by a the quantity $\pm T \frac{d E}{d T}$, in which T is the absolute tempe and E is the E. M. F. of the cell. Since the weights of mat liberated or consumed by a given current in a given time c definitely predetermined and the voltage due to a certain che combination can also be accurately calculated, almost any pr in electro-chemistry or electro-metallurgy is susceptible of quite easily and correctly solved. That branch of electro- istry and metallurgy which employs electrical heating meth also very definite, the exact amount of heat in gramme-de produced per second by an electric current being always giv the simple expression, $.24\, I^2 R$, or $.24\, E I$.

In support of the proposition advanced in the title o address, I am able to produce most interesting personal testin Mr. Edison and Mr. Tesla have independently expressed t their opinion that electrical knowledge had become so de and general that almost anyone could apply it, and comparat little opportunity was left for invention. They believed that chemistry and thermodynamics were far more uncertain and therefore offered a much better field for improvement. These views were expressed several years ago, and subsequent events have shown that they contain a great deal of truth. It is a fact that electrical engineering has advanced along the lines laid down by these and other great inventors, and it is also true that much of the work has been done by the rank and file of the profession. The trails blazed by the pioneers have since become broad highways with many branching roads, built for the most part by common workmen. On the other hand, the discovery of the Röntgen ray has since been made; and both of these investigators have given much valuable time to it. It would seem, therefore, that the electrical principles and laws of to-day are true for all time, and afford a firm foundation for unlimited future progress, but that there are also many additional facts yet to be discovered that are well worthy of the efforts of the greatest genius.

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[1] TRANSACTIONS, vol. v., p. 227.

In conclusion, the following quotation from the preface of Maxwell's great work on Electricity and Magnetism is appropriate. "The important applications of electro-magnetism to telegraphy have also reacted on pure science by giving a commercial value to accurate electrical measurements, and by affording to electricians the use of apparatus on a scale which greatly transcends that of an ordinary laboratory. The consequences of this demand for electrical knowledge and of these experimental opportunities for acquiring it, have been already very great, both in stimulating the energies of advanced electricians and in diffusing among practical men a degree of accurate knowledge which is likely to conduce to the general scientific progress of the whole engineering profession."

These words were written in 1873, and yet they show strong confidence in the accuracy of electrical methods and full appreciation of the close relationship between electrical science and engineering, as well as their beneficial effects upon each other. At that time the telegraph was the only practical application of electricity. What language would express Maxwell's wonder if he were alive to-day!

[COMMUNICATED AFTER ADJOURNMENT BY DR. A. MACFARLANE.]

[See p. 163 *et seq* for paper and discussion.]

I regret that I was unable to be present at the General Meeting of the INSTITUTE, but I am glad to have an opportunity of stating by correspondence the reply which I would have made to the points which were advanced in the discussion. First of all, I wish to thank Mr. Steinmetz and Dr. Kennelly for the favorable opinion which they express of the investigation proper; divergence of opinion exists only with respect to the bearing which the investigation has on certain principles of mathematical analysis.

The position in the paper which Mr. Steinmetz attacks may be thus stated. If the investigation in the paper is correct, then the current doctrine about the field and limits of algebra is incorrect. In order to state impartially the current doctrine, I took the very concise statement of it given by Mr. Steinmetz in his work on "Alternating Current Phenomena." It may be well to quote the paragraph in full: "Thus starting from the absolute integral numbers of experience, by the two conditions,

1st. Possibility of carrying out the algebraic operations, and their reverse operations under all conditions,

2nd. Permanence of the laws of calculation, the expansion of the system of numbers has become necessary into,

Positive and negative numbers,
Integral numbers and fractions,
Rational and irrational numbers,
Real and imaginary numbers, and complex imaginary numbers.

Therewith closes the field of algebra, and all the algebraic operations, and their reverse operations can be carried out irrespective of the values of terms entering the operation. Thus within the range of algebra no further extension of the system of numbers is necessary or possible, and the most general number is, $a + j\, b$, where a and b can be integers or fractions, positive or negative, rational or irrational" (p. 404).

Mr. Steinmetz and I agree in holding that the above is the view of the eminent mathematicians of modern times, but he holds that "it is obvious that they cannot possibly have been mistaken," while I hold that the investigation in the paper demonstrates that they have been mistaken.

Let us consider now the reasoning by means of which Mr. Steinmetz in his reply supports the current theory, and endeavors to show that the hyperbolic complex quantity is not an algebraic quantity. To simplify the question in dispute, we may accept the definition of an algebraic quantity which he gives, and admit the whole investigation down to $x^2 - y^2 = 0$. He assumes, and on this assumption hinges the whole matter, that this equation can be satisfied by finite values of x and y provided they are equal. But as x and y are the terms of a hyperbolic complex quantity, it is impossible for them to be equal, if they are finite quantities; in other words sinh φ is necessarily less than cosh φ. The hyperbolic complex quantities considered in the paper (p. 164) are $-a+\sqrt{a^2-b}$ and $-a-\sqrt{a^2-b}$; the quantity under the radical sign is necessarily less than the other. The expression x^2-y^2 means the square of the modulus of the hyperbolic complex quantity, and as x and y cannot be equal for any finite value, the equation $x^2-y^2=0$ can only be satisfied by both x and y being 0. In the case of the hyperbolic complex quantity, the two terms are at right angles to one another, and the vanishing of the modulus involves the vanishing of both terms for the same reason as in the case of the circular complex quantity. For the hyperbolic complex quantity the modulus $r=\sqrt{x^2-y^2}$ and the hyperbolic angle φ is such that tanh φ $=y/x$. Let using Kennelly's angle notation, one hyperbolic complex quantity be denoted by $r\,\underline{/\varphi}$ and another be denoted by $r^1\,\underline{/\varphi^1}$, then the product is $r\,r^1\,\underline{/\varphi\ \varphi^1}$ precisely after the manner of the ordinary (circular) complex quantity. If the product vanishes and r does not, than r^1 must vanish, and it can vanish only by x^1 and y^1 each vanishing. Hence the hyperbolic complex quantity is an algebraic quantity according to Steinmetz's own definition of such a quantity.

The investigation in the paper shows that the hyperbolic complex quantity is precisely analogue to the ordinary (circular) complex quantity; and for any theorem in circular trigonometrical analysis, there is a corresponding one in hyperbolic trigonometrical analysis. If the former is algebra, how is it possible that the latter cannot be algebra?

If my paper demonstrates anything, it demonstrates that the accepted theory of the quadratic equation requires to be improved in the way of extension; and one may reason that since the eminent mathematicians of modern times have not seen the complete theory of the quadratic equation, it is quite possible that they may have been mistaken about the field and bounds of algebra. The view of the quadratic equation which was held by the mathematicians of less modern times, was that if the quantity under the radical sign was positive, the solution was possible, but if it was negative, the solution was impossible. This is the true and complete theory, when the unknown quantity x is a linear quantity. However, when x is a quantity in a plane, the roots are possible, whether the quantity under the radical sign is negative or positive; in the former case, we have the circular complex quantity, and in the latter the hyperbolic complex quantity. The fact that the real roots are also capable of representation in the plane, is the part of the theory which has been missed by analysts, and is advanced for the first time in my paper.

For instance consider the quadratic equation

$$x^2-5x+6=0.$$

If x is a linear quantity, it is either 3 or 2; but if it is a planar quantity it is either $\frac{5}{2} + \frac{1}{2}$ or $\frac{5}{2} - \frac{1}{2}$, where the $\frac{5}{2}$ is the absissa and $\frac{1}{2}$ is the ordinate of an equilateral hyperbola. I may mention that since the paper was read before the INSTITUTE, I have applied this theory of the quadratic equation to the solution of the cubic equation, and have contributed the results to the Toronto meeting of the British Association.

Dr. Kennelly states very clearly some of the results to which the investigation in the paper leads. He omits by inadvertence to mention that it is the projection on the vertical axis of the motion described, which represents the electrical phenomenon. As regards the scalar $\sqrt{-1}$, we shall see that there must be such, if we investigate the proper analytical expression for a hyperbolic complex quantity. Suppose that the two components are x and y; as y is at right angles to x, it must be affected by the vector $\sqrt{-1}$ which may be denoted as usual by i; but as the modulus is $\sqrt{x^2 - y^2}$ instead of $\sqrt{x^2 + y^2}$ it may be reduced to the latter form by writing it $\sqrt{x^2 + (\sqrt{-1}\,y)^2}$. Hence the proper expression for the hyperbolic complex quantity is $x + i\,\sqrt{-1}\,y$, The $\sqrt{-1}$ here introduced is evidently scalar in nature. In my paper on the "Principles of Elliptic and Hyperbolic Analysis," I have advanced other reasons for believing in it. (p. 20).

The mistake to which Dr. Perrine refers is very apt to be made by one who does not perceive that a vector and a complex quantity are not the same thing. The former is a directed line, the latter is an angle associated with a multiplier. It is an entire mistake to call $a + b\,j$ a vector; its geometrical meaning is, an angle associated with a multiplier; and the product of two such quantities is another angle, which is the sum of the given angles, and a multiplier which is the product of the given multipliers. To say as do Dr. Perrine and Mr. Steinmetz that this product has no geometrical meaning is an entire mistake. When the multipliers are reduced to unity, the product expresses the fundamental theorem of circular trigonometry. Similarly the product of two hyperbolic complex quantities, when the multipliers are unity, expresses the fundamental theorem of hyperbolic trigonometrical analysis. Of course the product of two vectors is an entirely different matter.

A paper presented at the 14th General Meeting of the American Institute of Electrical Engineers, Eliot, Me., July 27th, 1897.

THE EFFECT OF HEAT ON INSULATING MATERIALS.

BY PUTNAM A. BATES AND WALTER C. BARNES.

A paper on this subject was presented before the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS on May 20, 1896,[1] by Messrs. Sever, Monell and Perry. In the discussion which followed, the results were questioned by several members, and Mr. C. F. Scott cited some investigations of Mr. Skinner, who obtained curves which differed very considerably from those shown in the paper.[2]

This left the subject in such an unsatisfactory condition that it was decided to make further tests with the object of reconciling the differences, or determining what the real facts are.

In our investigations, more attention has been paid to the actions which take place when one kind of material is subjected to tests while the conditions are varied, rather than to a great number of tests on different materials, under the same conditions.

In fact, it has been deemed wise to conduct all the tests on one kind of material, it being safe to conclude from results previously obtained, that the action on it would be quite similar to that produced on other samples. Therefore, the ordinary "red fibre" insulating material having the general appearance of thick red paper, has been selected. Its thickness is about .009 inch.

THE APPARATUS.

This consists of two distinct parts, viz: the device for heating and that for testing the insulation resistance. The heating apparatus consists of a single electric heater, having a radiating surface of 47 square inches. This is nothing more than six resistance coils tightly packed with asbestos in a short sheet iron cylinder, whose lower end is open. The terminals come from the ends of this set of resistance coils through the bottom of the heater, and are then connected through a suitable switch to a 110-volt circuit. This heater is supported on three porcelain insulators, which rest on a slab of slate one and one-half inches thick and one foot square. The heater takes exactly four amperes of current when all other resistance is cut out of the circuit.

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[1] TRANSACTIONS, vol. xiii, page 223.

[2] *Ibid*, page 237.

Around the heater is placed an earthenware cylinder one foot high and nine inches in diameter. This provides an excellent method of keeping the heat in, and together with the electric heater secures perfect regulation of temperature. The terminals of this heating circuit are brought directly down and out from the heater through the base slab of slate to the terminals of a 110-volt lighting circuit and are thus kept entirely separate from any other part of the testing apparatus.

Resting on an asbestos collar and at a height of about 2 inches above the heater, in the earthenware cylinder, is placed a circular iron plate $\frac{1}{8}$ inch thick, which is one terminal of the testing circuit itself, and is connected to one binding post of a Thomson high resistance galvanometer; a standard megohm being placed in series between the two.

The insulating material to be tested is wrapped on an iron cylinder 3 inches in length and having an external diameter of .875 inch, the insulation not quite reaching to the ends of the cylinder. The insulation is then wound with No. 26 B & S bare copper wire. This winding makes the other terminal of the testing circuit, and is connected to the other post of the galvanometer. The iron cylinder, upon which the insulation is placed, is then placed upright on the above mentioned iron plate. Thus it will be seen that the insulating material now separates the copper wire winding, as one terminal, from the iron cylinder which is now in contact with the iron plate, as the other terminal. The leading-in connections to these terminals pass through small holes bored in the earthenware cylinder. Glass insulators are used in these holes in order to prevent any current from creeping across from one wire to the other over the surface of the earthenware. Heavy covers of asbestos board are placed over the top of the earthenware cylinder and this again is entirely covered with a large glass globe.

The potential used in this circuit is 500 volts. A suitable shunt, consisting of one or two turns of bare copper wire wound on each end of the sample of insulation, so situated that they would intercept and shunt past the galvanometer any current tending to leak along the surface of the insulation from the iron cylinder to the winding, that is, from one terminal to the other, is used in order that a deflection of the galvanometer needle will be produced only when a current actually passes through the insulating material under test.

In making the apparatus we have been very particular to eliminate all metals, with the exception of iron and copper, thus avoiding any possibility of the volatilization of zinc, which was one of the points raised in regard to the previous tests.[1]

This apparatus when complete works admirably, absolutely no difficulty being experienced with either the heating or the testing circuit.

The questions that we have attempted to answer by this investigation are four in number, viz.:—

1st. Does the presence of brass or other metals from which zinc may become volatilized, in the apparatus in which the test is conducted, affect the insulating material or its behavior?

2d. Why should one experimenter obtain an insulation resistance curve for fibre, whose minimum point is at about the same temperature as the maximum point of an insulation curve obtained from similar material by another experimenter?

3d. What effect on fibre insulating material is produced when it is subjected to conditions similar to those likely to occur in dynamo-electric machinery?

4th. What is the action, or actions, that take place when fibre insulating material is repeatedly heated from 20 degrees C. to 200 degrees C.?

Question No. 1 has been approached in the following manner: the resistance of the insulating material at the temperature of the air, or 20° C., being determined, the temperature is gradually raised until 200° is reached, when the test is discontinued. The time taken for this rise was exactly 2½ hours. Resistance measurements are made at frequent intervals, and from these curve No. 1 is plotted. The area of insulation tested being 5.5 square inches thickness = .0095 inch.

The position and shape of this curve agrees very closely with the results obtained by Messrs. Monell and Perry, who in their experiment used a brass cylinder, but a confirmatory test with a brass cylinder was also made in our apparatus. This experiment, was deferred until the completion of all other experiments.

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[1] TRANSACTIONS, Vol. XIII, page 233.

Curve No. 2 thus obtained from a like sample of insulating material, thickness .0095 inch, area tested = 4.6 square inches, showed that the presence of brass in the apparatus does not affect the shape or position of the curve.

In taking up question No. 2, it is intended to prove, by comparative tests, that the position of the maxima and minima points of the resistance curves, depend upon the opportunity of escape given to the moisture originally contained in the specimen.

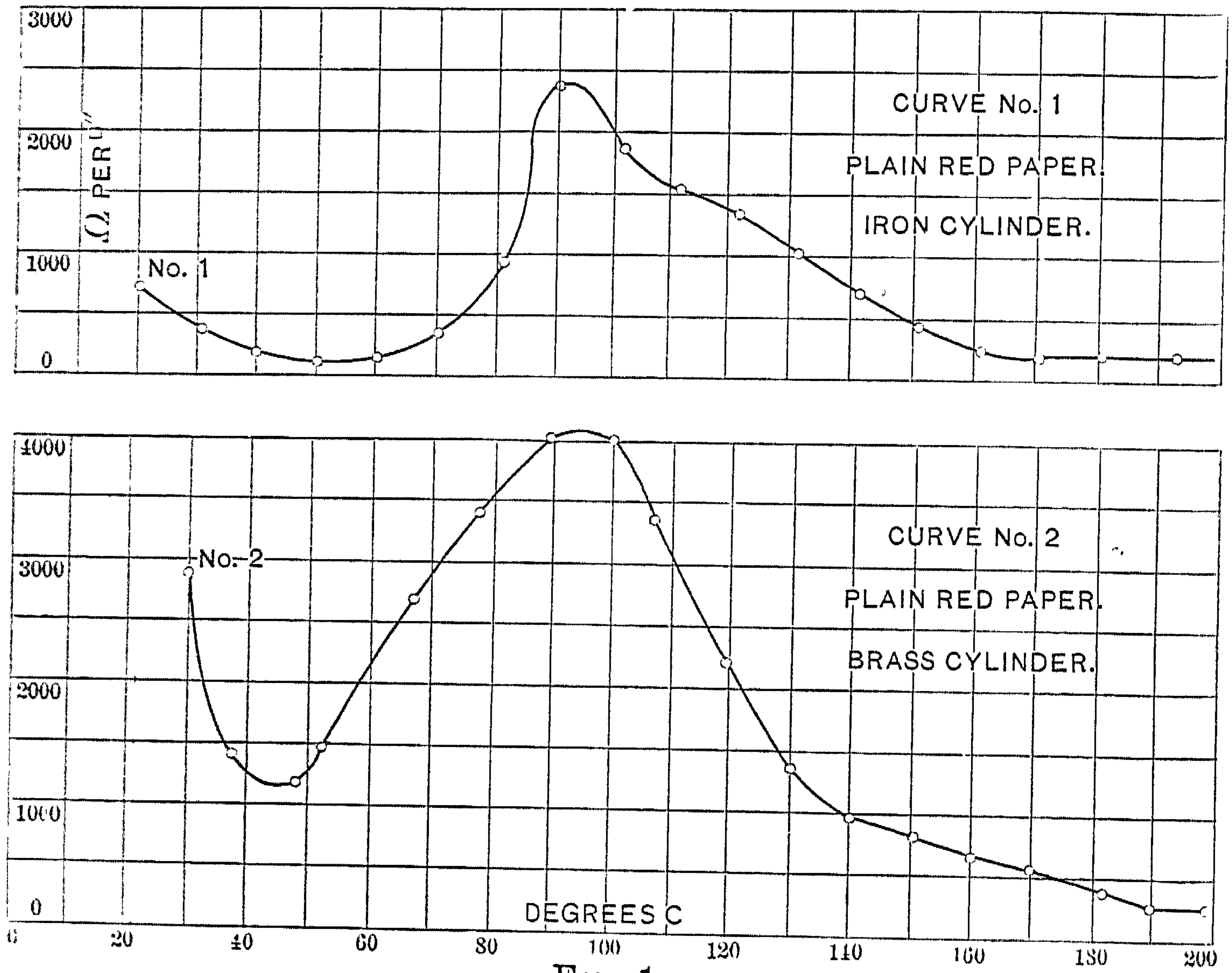

FIG. 1.

Curve No. 3 shows the results from a test on a sample of plain red fibre, thickness .009 inch, the area of insulation under test being 2.2 square inches. In this case five layers of No. 26 B. & S. bare copper wire were wound closely upon the fibre, the length of winding being only .8 inches.

Curve No. 4 has been obtained from a test on a specimen cut from same sample wrapped with a sheet of thin malleable iron held firmly in place by a number of layers of tightly wound copper wire, thus approaching the conditions under which the experiments cited by Mr. Scott were made. The area covered by this iron wrapping is 6.75 square inches. This test consisted as before in gradually raising the temperature from that of the air to 200° C., the resistance being measured at frequent intervals. The curve obtained under the above conditions is almost identical with that published by Mr. Scott.[1]

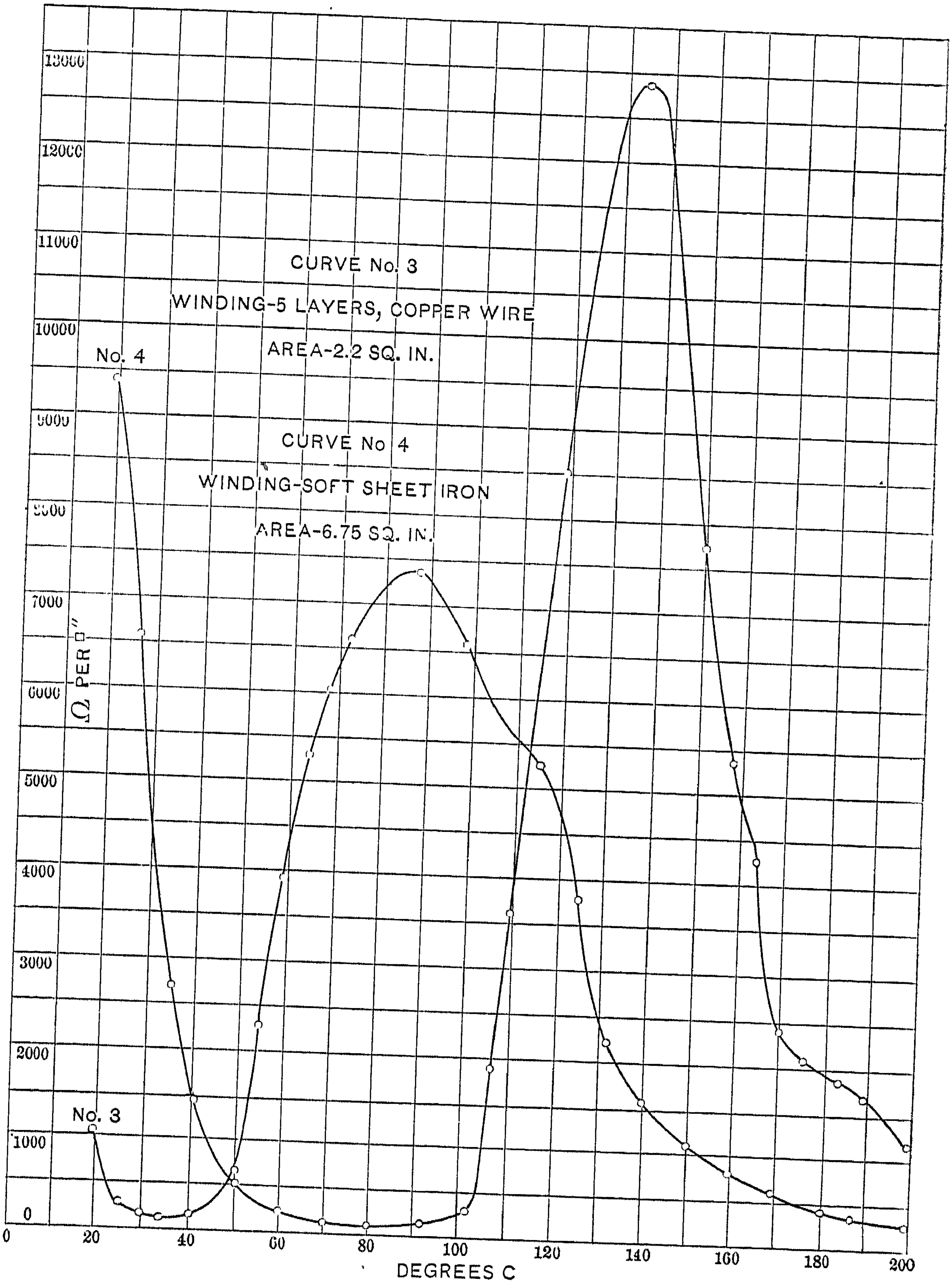

Fig. 2.

It is clear from these two experiments that the position of the curve may be shifted at pleasure by simply varying the opportunity for the escape of the moisture originally contained in the insulating material. That is to say: if we wind our specimen with wire and only cover a small area, we find that the moisture has a much better chance of escape than if completely covered with an iron wrapping extending over a large area, and that the curve will actually take a position depending upon the rapidity of escape of the moisture. In the case of the wire-wound specimen the moisture escaped not only through the interstices between the wires, but also, and to a much greater degree, from the exposed ends which it reaches through the pores of the material; while with the iron-wrapped specimen the only chance of escape is from the exposed ends. Therefore, the greater the area covered, the longer will be the path traversed by the moisture and consequently a longer time or higher temperature will be required.

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[1] Transactions, Vol. XIII, page 239.

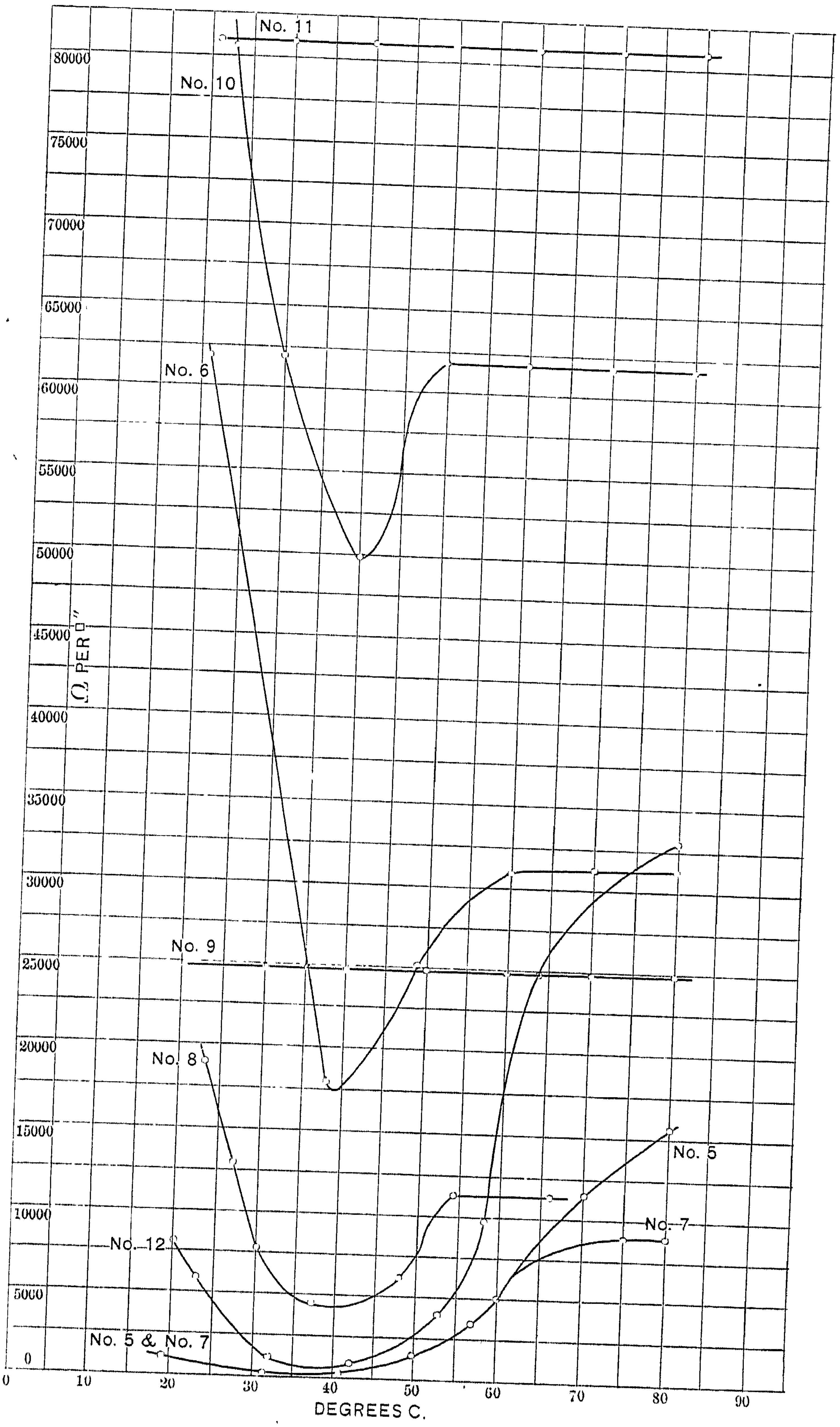
Question No. 3. A new specimen of plain red fibre .009 inch thick was wound with four layers of No. 26 B & S bare copper wire, the area covered being 4 squàre inches, and then subjected to the variations in temperature and exposure to moisture which are most likely to take place in dynamo electric machinery.

Insulating material when used in this way is subjected to repeated heating and cooling, being kept at a moderately high temperature for varying lengths of time, also being exposed more or less to the moisture in the air. Therefore, the following eight tests have been made under conditions approximating the above and upon the above described specimen.

In all of these tests the temperature is gradually raised from that of the air, 20° C., to 80° C., at which temperature it is kept constant for $3\frac{1}{2}$ hours. The time taken to raise the temperature this amount is about 45 minutes.

Curve No. 5 has been obtained from the first heating. The specimen was then allowed to stand unexposed to moisture for 16 hours, at the end of which time a like test is made, giving curve No. 6. After a lapse of 24 hours, during which time the specimen was exposed to the atmosphere, which was very damp, the temperature is again gradually raised and kept constant as before, curve No. 7 resulting.

It will be seen by examination of these curves that the specimen after exposure to moisture returns to its original condition. The method of exposing the specimen to moisture is to remove the glass globe from the apparatus and the asbestos covers from the top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DEGREES C.

Fig. 3.

of the earthenware cylinder, the specimen itself being undisturbed. Three days, (72 hours) having elapsed, the specimen being undisturbed and unexposed to the atmosphere, is subjected to further test, giving curve No. 8.

Great care is now taken to protect the specimen from all moisture for 16 hours; at the end of which time, upon again testing, curve No. 9 is obtained. The test consisted, as before, in raising the temperature to 80° C., where it was kept constant for three and one-half hours.

All covering is now removed and the specimen allowed to cool to 23.3° C., the time occupied being three and three-quarter hours. Curve No. 10 is then obtained upon reheating.

Again great care is taken to protect the specimen from disturbance and all moisture for nineteen hours. On being again subjected to test, curve No. 11 results.

Now the specimen is allowed to stand for exactly five days freely exposed to the moisture of the atmosphere, it being situated in a room near a window which is left open a considerable portion of the time, thus subjecting the specimen to conditions of atmosphere similar to those occurring in a station or factory.

The weather during the five days was unusually damp. A number of severe rain storms occurred, thus giving the specimen an extremely good opportunity to absorb moisture. At the end of this time a test was made, from which curve No. 12 was derived.

The object of this test is to see if, after exposure to moisture, the material will return to its original condition. By a glance at the curve thus obtained it will be seen that this actually takes place.

Let us now compare the eight curves. Curve 5 represents the original resistance variation of the material. Curve 6 shows the increased initial resistance on cooling, the specimen having been protected from moisture in the meantime. Curve 7 shows the return to the original condition on absorption of moisture. Curve 8 the higher value of the resistance curve when the specimen has been kept at 80° C. for three and one-half hours and then allowed to cool, but not exposed to moisture. Curve 9 shows that the heating up to 80° C. has practically no effect on the resistance after the moisture has been driven out and not allowed to return. Curve 10 shows the condition into which the specimen was thrown when cooled while exposed to the atmosphere. Curve 11 indicates that the moisture had again been practically all expelled and therefore, the heat produced no change in the resistance. Curve 12 shows that the specimen having been freely exposed to moisture has returned to almost its original condition. In all these

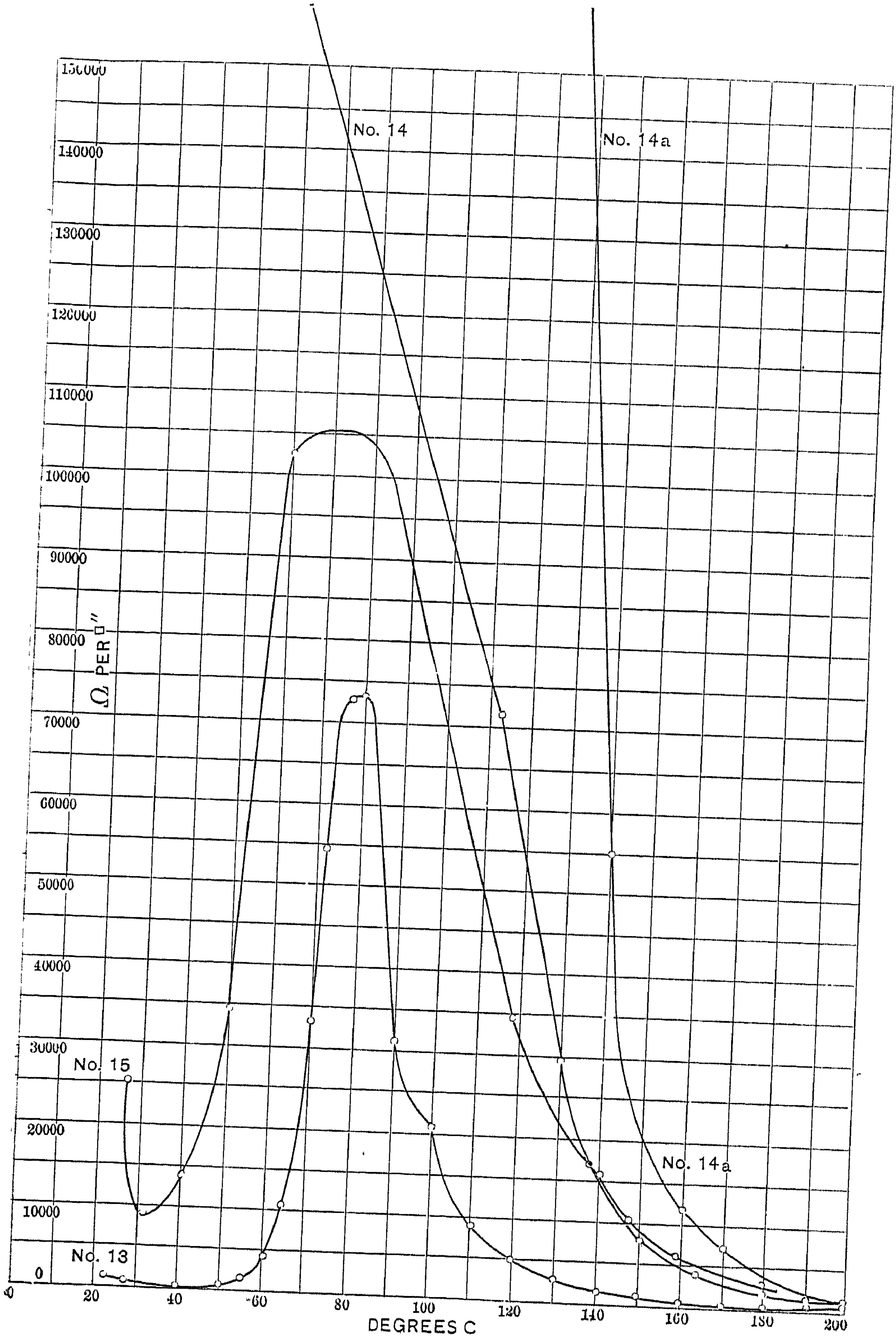

FIG. 4.

tests the resistance remained constant during the entire time that the temperature was kept constant. On examination, the specimen was found to be practically unchanged in appearance, mechanical strength or other qualities. One might, therefore conclude, on inspection of the various curves in connection with these experiments, that the action which takes place in a fibre insulating material when heated up to about 80° C., merely depends upon the amount of moisture contained in the material at the time at which each measurement is made.

Question No. 4 may be answered by reference to the curves obtained from the three tests on one piece of insulating material wound with four layers of No. 26 B. & S. bare copper wire. Area of insulation under test was 4.125 square inches, and the thickness was .009 inch.

Curve 13 is the resistance curve for the first heating from 20° C. to 200° C.

The descending portion of the curve between 23° C. and 40° C. is probably due to the coalescing of the moisture within the material; that portion between 40° C. and 80° C. shows the rise in resistance due to the expulsion of the moisture and the remainder the negative resistance coefficient which insulators usually possess.

This test being completed, the specimen was allowed to stand undisturbed and protected from moisture for twenty-four hours. Upon reheating, Curve 14 was then obtained. This shows the rapid drop from the enormous resistance acquired by the material on cooling from the previous test.

While the specimen was cooling from the heat applied in test 14, frequent measurements were made, resulting in curve (14*a*), which shows the rise to a still higher resistance than before. At 100° C., the resistance was too great to be measured by the apparatus at hand.

Now the specimen was allowed to stand undisturbed for thirty-six hours, during which time the air in the apparatus was kept moist. Curve 15 was then obtained on repetition of the test, showing that the material when repeatedly heated to 200° C. still retains its property of absorbing moisture, and the effect upon its insulation resistance is not as great as would be expected. But it should be noted that this high temperature of 200° C. greatly injures the mechanical strength of the insulating material.

From the foregoing we may derive the following general conclusions:

a. The presence of brass in the apparatus does not affect the shape and position of the curve.

b. The difference in the curves depends solely upon the amount of moisture contained in the material and its opportunity of escape.

c. Every time the specimen cools, the resistance increases to a value much above any resistance that it possessed before, provided it is kept from absorbing moisture.

It is impossible to determine the limit of this action with the present apparatus. But all the curves, particularly Nos. 5 to 13, clearly show this stepping up effect, which is practically the same as the well known result obtained by baking insulating materials.

Discussion.

The President:—This paper, as stated in the introduction, is the result of work taken up in order to reconcile the extreme differences that were pointed out by Mr. C. F. Scott when the paper by Messrs. Sever, Monell and Perry was read at the last General Meeting, May 20th, 1896. It seemed to me that leaving on the records of the Institute a practical and important matter of this kind with such great differences of opinion was extremely undesirable, and therefore the attempt was made to ascertain the true facts. Mr. Scott made the statement that experiments with which he was familiar, obtained the minimum resistance exactly where the other investigators had obtained the maximum value. That discrepancy is entirely explained in the way that I suggested in the discussion of the paper at the time, by the curve shown in Fig. 2, when you will note that the maximum in curve No. 4 is about 85° C., and the minimum in curve No. 3 is at 80° C. That difference is entirely due to the fact that in one case, curve No. 3, the material was wound with copper wire, the interstices between the turns allowing moisture to escape somewhat freely. In the other case where the maximum as well as minimum points were shifted to the right, the insulating material was wound with sheet iron, and a much longer cylinder of insulating material was tested; consequently the opportunity for escape of moisture was much less, and the result was obtained just as expected. But the fact that the maximum and minimum points can be shifted to the right or to the left in this way is absolutely proved and is, I think, a matter of some practical importance. Furthermore, it is also shown in the curve given in Fig. 3, that the behavior of this insulating material between 20° and 80° C. is simply dependent upon the moisture that it contained, and that after driving off that moisture and allowing it to return, the material regains exactly the same condition as before. Therefore we can control entirely between those limits the position of the curve by the amount of moisture that we allow to enter the material after having driven it out. Those two points I think, are of interest and importance. The curve shown in Fig. 4 represents the effect produced by much higher heating up to 200° C., and while very high resistances are obtained, running into the hundreds of thousands of megohms per square inch, it should be remembered, as pointed out in the paper, that the mechanical strength of the insulating material is very much affected, and that while we get what might be called laboratory results of high resistance, the material is not in a condition which would make it at all suitable for use in practical electrical machinery; but up to 80° C., which is the ordinary limit, apparently, no permanent effect is produced. It is simply a question of how much moisture is allowed to enter and how much to escape. The exact limits at which material becomes permanently injured is not an electrical question; it is a mechanical one; because the insulation resistance is very high even after the material is badly affected; hence, it is rather difficult to set a limit. Probably some test as to the strength of material, its tensile strength for example, would be the best way to determine that point,—or its resistance to mechanical puncturing or possibly electric puncturing. That however has not been done. But the question of the effect of temperature upon insulating material is one of vital importance in electrical engineering, because our most serious difficulties arise from the breaking down of insulation, very often due to excessive temperature.

The paper is open for discussion.

DR. PERRINE:—Both at the time the earlier paper was read and at the time I first saw this paper it was a matter of great surprise to me that there should not have been more knowledge of these facts disclosed by the electrical engineers, particularly as I knew that there were so many men in the body who were familiar with work in paper cables and similar experiments where the investigation of moisture in insulation was made necessary. What this paper proves, and what should be more or less a foregone conclusion, is that if you have moisture in the insulation the temperature co-efficient is a co-efficient largely of the moisture itself, and furthermore, that the amount of moisture determines the specific insulating resistance of the material. Again we know that these materials, such as fibre and paper, retain in comparatively dry air, a large amount of moisture. In drying paper insulated cables, taking a 100 pair cable wrapped to 128/1000ths. of an inch of paper, and using No. 18 wire; more than four per cent. of the weight of the combined paper and copper is in the moisture which may be driven off by proper drying, and in the paper itself, from 15 to 20 per cent. is moisture, in the driest air you can find. Last year I had some experiments tried in summer in California, where the air is drier than we almost ever see it here, and wood that was thoroughly dry would in two days absorb from 13 to 15 per cent. of its weight in moisture. This being true it is not by any means surprising that the temperature co-efficient of any material would largely depend upon the moisture contained in it. Compressed paper and fibre hold less moisture than wood or the ordinary manila paper used in wrapping cables. But at the same time all of us who have been through the harassing experiments in making commutators with fibre which was the practice ten years ago, know that the best of the compressed paper and the best of the fibre that we can obtain, contains enough moisture for it to change in its dimensions after being dried out. Not less than five per cent. of the weight of the best compressed paper made to-day is water in dry air. It does not need exposure to moist air. But air as dry as this or drier will enable the best quality of compressed paper to hold at least five per cent. of its weight in moisture. Now this being so, as I say, it is not at all surprising that we should find the temperature co-efficient of the insulating material, under such conditions, is a matter of the amount of moisture in it, and it is surprising to me that experiments should have been made within the last five years on insulating materials which intended to give the temperature co-efficients of the insulating materials themselves, and no effort made to remove the moisture before the test were commenced. The matter of removal of moisture is also a difficult matter. The curves on page 259 show that. On repeated heating the resistance rises and rises, and every time you heat it, even keeping the specimen in what you call dry air of the receptacle in the laboratory—not simply exposing it to the dry air of the laboratory, but keeping it as nearly dry as possible, and by repeated heating you will drive off a little more moisture each time you bring the temperature up, and in consequence the insulation resistance will rise, finally approaching a maximum. Again, we know from our experiments in paper cable working that it is not necessary to destroy the mechanical properties of the insulation in drying it out; for it is not necessary to dry paper or fibre or anything else above 100° C., or even as high as 100° C., if we dry by means of perfectly dry air in a desiccator; and that is the only means by which the moisture can be eliminated with any degree of completeness at all. The attempt to drive off moisture by heating, is a question of the humidity of the atmosphere with which your specimen is surrounded. In the ordinary baking ovens of the electric factories—at any rate as they were made ten years ago, when they were simply baking ovens—we found, that in the cold dry weather of the winter-time we could dry out armatures in 24 hours, more completely than we could dry them out in a week in the summer time, when the atmosphere was moist, and although the same difference of temperature between the outside and inside air was obtained. It is simply a fact that the air has a certain capacity for absorbing moisture, and so has the insulating material a capacity for holding it, and the question of desiccation depends upon the relative amounts of moisture held by the insulating material and by the air. If your air at a certain temperature is saturated, the air will not dry out the insulating material. If you raise the temperature of the air and the air has been previously saturated, you then increase the capacity for moisture of the air slightly, but you cannot thoroughly dry out an insulating material, unless you pass over it air which has previously been thoroughly dry, and when you do this there is no necessity to raise the temperature of the insulating material so as to destroy its mechanical quality. Indeed in the cold, we may thoroughly dry out an insulating material by the use of a desiccating material if we give it time enough. The application of heat simply hastens the time of removal of the moisture, and in consequence the application of a certain amount of heat is advisable, but it is not by any means necessary. The moisture within the insulating material and in the air is in a constant state of interchange, just as there is an interchange with a glass of water standing in the air. As we have a certain vapor density, that vapor density is not changed by the fact that moisture is absorbed in the interstices of the insulating material, and if the moisture goes out and is absorbed by some desiccating material, then we have a vapor vacuum for the remainder of the moisture, and more will be given off until finally our insulating material becomes dry, and that without producing any mechanical injury whatever. There is nothing new, as I say, about these facts I am giving you. This has been the experience with all paper cables made during the past ten years. Any cable manufacturer knows that it is perfectly easy to talk from one wire to another in a paper cable as soon as it has been laid together in the factory before it has been dried out. With a telephone it is sometimes difficult on a thousand feet of cable to distinguish between wires. This is simply on account of the presence of moisture in the insulating material, and that difficulty is entirely removed, and we begin to get insulation only after the moisture has been removed.

So far as the temperature co-efficient is concerned, moisture being present as shown here, it is not a temperature co-efficient of the insulating material at all. This paper simply confirms our knowledge of the fact that compressed paper and fibre absorb moisture readily, and are unreliable as insulating material—a knowledge which has altered the construction of most of our electrical machinery, for where great reliability was necessary, compressed paper and fibre have been entirely removed, and not within at least five years, perhaps, have these materials been used where reliability was considered necessary, and that simply because the presence of moisture in the material has been understood as the reason that compressed paper was not a reliable insulating material.

The President:—Of course it has been known for many years that the effect of moisture on insulating materials was deleterious, and furthermore, that all such materials as paper, cotton etc., contained a great deal of moisture, and that they would absorb it from the air and retain it, and even though the air was what we commonly call dry, they still contained a large percentage of moisture. That general fact is common knowledge; but it was not known generally that the effect between 20° and 80° C. was due to nothing but moisture; that there was practically no temperature co-efficient. Furthermore, a year ago, at the meeting of the Institute, no one was able to explain the extraordinary discrepancy between the results given in the paper then presented, and the results cited by Mr. Scott. The experience with paper cables which Dr. Perrine has had, makes him especially familar with this subject, but all of us have not had that experience. Furthermore, I would suggest that it would have been desirable if Dr. Perrine at some time had presented a paper to the Institute on this subject.

DR. PERRINE:—I am very sorry that I did not The only reason I had for not doing so was because I thought it was common physical knowledge. Open any text-book and you will find it stated there that wood and paper will hold in dry air from 15 to 25 per cent. of moisture, and it seems to me when one-sixth at least of the insulating material is water, we would naturally look to water as giving us our temperature co-efficient, and it did not occur to me at the time I was working at the thing that there was anything new about it at all, because you will not find a book on fuels that does not give you that information.

THE PRESIDENT:—That is a general qualitative fact, Dr. Perrine. I am talking about the specific curves that are obtained for insulating materials, and as I say, a meeting of the INSTITUTE at which many prominent members were present, including those particularly engaged in this line of work was unable to solve the problem. That is a matter of record.

DR. PERRINE:—I will tell you where I think you will find this thing—not exactly in curves, but you will find statements of the fact. In 1862 there was a conference called in relation to the possible laying of an Atlantic cable, where insulating materials were discussed, and this question of moisture in its value of changing the insulating material and the temperature co-efficient in insulating materials was pointed out in connection with some of the points then presented before the telegraph conference. It is printed in one of the English blue books, and I think you will find most of this material there.

THE PRESIDENT:—The general fact is one thing, as I say, and the specific curves another. Dr. Perrine is continually stating that it is a matter of common knowledge. Ever since dynamos have been used they have been provided with water-proof covers for the reason that the actual dripping of water upon them is most objectionable. But that is not exact physical knowledge, and I simply refer to the TRANSACTIONS of last year for proof of the fact that a largely attended meeting of the INSTITUTE could not explain the discrepancy there brought out.

PROF. THOMSON:—I think there is no question that as a qualitative fact it has been known that the presence of moisture is to be avoided in insulating material, and also the fact that cellulose if sufficiently heated becomes a dielectric, and will remain charged —the old experiments with rubbed paper prove that; still I think that the paper has brought out and put in a precise shape just how variations of insulation have occurred. Whether these matters have been fully investigated or not, and published in other papers I am not aware. I have not come across any curves of this kind. There are, however, other facts in connection with cellulose as an insulator, which I think have made it less desirable than other materials. It is a substance which is not by any means stable at high temperatures; even a temperature below 100° C., runs it down or carbonizes it slightly, so that finally it becomes an entirely different chemical substance. Some experiments were made several years ago, I think as much as ten years ago for that matter, in the Thomson-Houston factory. We subjected cotton covered wire to varying temperatures for long periods of time, and found that even at 100° C, there was a gradual deterioration and that at any point much above 100 it was pretty rapid. The cotton turned brown and showed every evidence of a permanent loss of water and an increase of carbon relatively to the hydrogen and oxygen. We all know as a fact that browning and deterioration actually occurs at ordinary temperatures through very long periods of time. We see the old books in the libraries turn brown from the same cause. The substance cellulose, in other words is not stable, and a high temperature simply brings out the instability or makes the time required to change the substance less.

PROF. WILLIAM ESTY:—I enjoyed hearing the discussion of the paper and the paper itself, and would jnst like so say that at the University of Illinois, two of our seniors last year made very similar experiments on different materials, giving results that agree substantially with those published in these TRANSACTIONS. There was one point of difference in our experiments, and that was in the method used to heat the materials. Here it was an electrical method, using a number of resistance coils, whereas we used a cast-iron cylindrical vessel in which the material, in the form of a circular disk, was placed between two iron plates. Then a sort of cylinder-head top was screwed on to this flat vessel and the whole immersed in boiling oil or heated oil I should say. The temperature at starting, of course, was about that of the room, the cylinder oil being heated slightly by means of two or three gas jets—Bunsen burners—and the temperature could be increased quite regularly, although it was a rather slow process; till 100 or more degrees centigrade was reached. It took a good deal of time of course to get the temperature where it was desired, but the method, as I say, was quite satisfactory.

There is one other point I wanted to find out about in this paper, and that was the source of electromotive force. It was stated I think at 500 volts,—but not the source of E. M. F.—on page 254. I would like to ask Mr. Bates what was used.

MR. BATES:—A motor dynamo was used to transform the potential from 110 to 500.

PROF. ESTY:—We found on trying a 500-volt dynamo that the galvanometer gave quite unsteady readings. The circuit acted as though it had electrostatic capacity, as doubtless it had. We had a sort of condenser effect, with those two plates, upper and lower, with the insulating material between them as a dielectric, and we found that the unsteadiness in running the dynamo made it absolutely impossible to get any reliable results. The galvanometer needle if once started to the right would continue to the right, but by getting it once started to the left it would go to the left;

so that what we finally adopted was a storage battery, one that we made—of small cells and a good many of them. We got up to 600 volts, which was quite satisfactory, and all disturbances of the galvanometer were eliminated. Another thing we found that required a great deal of attention, and of course that goes without saying, that the insulation of all the apparatus—glass insulation—could not be depended upon in the ordinary way. But all the circuits having been made air lines and everything arranged with the utmost precaution to avoid leakage anywhere, the results we obtained on a number of substances, linen and fibre and the ordinary insulating materials, were substantially the same results as shown in this paper; that is the effect of moisture, and again the effect of pressure between the two plates. between which the material was placed, made a great deal of difference, of course. The way we tried to reduce the results to a uniform basis was to take a five pound lead weight, place it on the upper plate and use the same weight throughout all the experiments. That eliminated any possible uncertainty as to the pressure which would be introduced by wrapping the material on to a cylinder by means of a wire, unless that wrapping produced just the same pressure in every case, otherwise it would hardly be correct, it seems to me, to draw conclusions from these different conditions; but this uniform weight enabled us to say practically that all material was subject to exactly the same pressure. It is needless to say that by adding to the pressure we found the insulation resistance would drop very quickly, and removing the weight, of course, brought up the insulation resistance.

There is just one other point that I wanted to speak of, and that was what seemed to me desirable in the reduction of these results, viz. insulation resistance per square inch. I think this is the first time I have seen that reduction to unit of area, but should think that the addition of the thickness to that unit might be desirable. For instance, I would plot megohms per square inch per mil thickness, and then we could compare all our results and perhaps get conclusions more readily than where these units differ. I think in the former paper that is referred to here, the one by Messrs. Sever, Perry and Monell, that no reduction whatever to a unit was given—but simply megohms, and here megohms per square inch. In the results that we got last year at the University of Illinois we reduced to megohms per square inch per mil of thickness.

MR. STEINMETZ:—With reference to the instability of the galvanometer dynamometer observed by the last speaker, I observed the same phenomenon some years ago and found the source of it in the mutual induction between the two coils of the instrument which, with a leading current load as a condenser, produced an unstable equilibrium. Now coming to the paper—this paper is very interesting and valuable in-so-far as it extends the amount of information on insulating material available to the electrical fraternity by publication. There are three distinctly different phenomena taking place in the insulating material. The one is the changing of resistance of the insulating material proper, with temperature; the second is the effect of the moisture retained by the insulating material, and the third is the chemical disintegration taking place. I may say that the separation of these three phenomena would be very desirable. It would be much more easily accomplished by using instead of the "resistances" the "conductivities" of the insulating materials. Then, I think, we could with some observations separate the three distinct effects, and get the electric conductivity of the insulating material proper, and such curves, of exponential or logarithmic nature, have been, I believe, observed on materials which are not hygroscopic, as hard rubber, gutta-percha, etc. A further conductivity, representing a resistance increasing with the temperature, not linear but rather erratic, superimposed upon the conductivity of the insulating material proper, is the conductivity due to moisture included by the material, and this as before said is entirely erratic, depending absolutely on the atmospheric conditions and the chance of the moisture to be absorbed or to escape. Furthermore there is a chemical disintegration taking place which changes the material and which depends again on temperature and on time.

I will draw attention to one feature which may very easily cause misunderstanding, namely, the effect of chemical disintegration in lowering the insulation resistance, and the effect of moisture in lowering it. There is an enormous difference in their practical bearing. Moisture, while reducing the insulation resistance, is, within a reasonable range, perfectly harmless. It is useless to exclude it, because as soon as the electric machines come into operation they will absorb moisture again just the same.

Thus the only object of expelling moisture by baking is to get a sufficiently high number of megohms insulation resistance, to fulfil some antiquated set of specifications.

I am glad to state that more and more consulting electrical engineers come back from this question of the megohms insulation resistance as a guarantee of the safety of insulation of the machine, and instead of it specify the voltage at which the insulation should not be punctured. If the insulation is fibre and is very bad, it will be punctured at low voltage and still, after baking show an enormous insulation resistance, while a very good insulation, after long exposure to damp air—as in a turbine station—may be of relatively low insulating resistance and nevertheless far superior to the infinite number of megohms which break down by disintegration or puncture at low voltage. Fortunately now you very seldom find an electrical engineer sufficiently behind the times to request a large number of megohms. If this is the case he gets it by baking the apparatus—otherwise baking goes more and more out of use, and its place is taken by the high voltage or puncturing test.

Obviously moisture, while fairly harmless when in small amount, must not be excessive—that is the armature must not be dripping with water, which all the same happens occasionally, when machinery shuts down evenings, and the dew accumulates on it over night. Even then it usually does no harm. So you see you must distinguish between the low insulating resistance due to moisture, and that due to imperfect material or chemical disintegration.

PROF. THOMSON:—There is just one point I would like to call attention to—I meant to speak of it when I was on my feet before—and it is in regard to the curves on page 259, Figure 3. It would appear that when the moisture was dried out of the material and the cooling took place, that there was no temperature co-efficient properly so-called. No. 9 and No. 11 are practically straight lines and that would seem to negative any idea of a variation of resistance, at least within those limits due to temperature of the dry material.

DR. KENNELLY:—The discussion has been interesting in showing the different standpoints which may be assumed by different readers who have not tacitly agreed upon the exact question at issue. When the original paper, referred to at the outset, was read, I think I can remember that the subject was not treated as a discussion of a true physical constant i. e. a temperature co-efficient of variation in resistivity of heated insulating materials, because it was generally understood, although perhaps not stated, that the variations in resistance observed were much more erratic than could be expected from a true temperature-co-efficient. As Mr. Steinmetz says, you cannot expect to come within measuring distance of a temperature co-efficient until you have driven off practically all the moisture from the test piece. Prof. Thomson has pointed out that, apparently, when this was done, the curves Nos. 9 and 11 of this paper indicate an absence of temperature variation between the limits of 20° and 80°. Dr. Perrine, however, seems to have considered that we discussed the existence of a real temperature co-efficient when the original paper was read. It is, of course, generally known that paper and fibre absorb much moisture at ordinary temperatures, and in the presence of that moisture all real temperature variations are necessarily obscured. The question discussed was why the particular curves accompanying that paper showed humps or maxima at positions very different to those observed by Mr. Scott. No satisfactory solution of this question seemed to be offered. I think we are indebted to the writers of this paper for an explanation of that phenomenon. They seem to show that everything depends upon the facility and speed with which the moisture is driven off in the test.

We cannot suppose that a material such as cellulose can have a real resistivity unless a number of conditions are stated, such as absence of moisture, pressure, degree of purity, etc. For this reason, perhaps, we should be grateful to the authors of this paper for having referred their results to absolute insulations only, and for not having computed them as resistivities referred to the cubic centimetre. For had they stated their results in the form of resistivity, we might have been inveigled into the belief that such was a real physical constant of the material; whereas it was probably a function of a number of local conditions any variation in which might have led to a different numerical result.

The following paper on "The Effect of Armature Induction upon the Electromotive Force Curves of an Alternator" was then read by Prof. W. E. Goldsborough.

A paper presented at the 14th General Meeting of the American Institute of Electrical Engineers, Eliot, Me., July 27th, 1897, Vice-President Steinmetz in the Chair.

THE EFFECT OF ARMATURE INDUCTANCE UPON THE ELECTROMOTIVE FORCE CURVES OF AN ALTERNATOR.

BY W. E. GOLDSBOROUGH.

The subject of the regulation of alternating dynamo-electric machines, considered as a function of the inductance of their armature coils, has been treated by a number of writers, and during the last few years has attracted much attention.

In looking up the bibliography of the subject, however, I find that but few records have been published of the actual value of the inductance of the generating coils of these machines, and that even less data are available regarding the real nature of the periodic fluctuations that take place in this quantity.

We are indebted to Hopkinson, Ayrton, Kapp, Sumpner, Duncan, Tobey and Walbridge, Reid, Steinmetz, Fleming, Rothert, Roessler and many others for much valuable information touching upon the theory and practice of the design and handling of machines of this type, but these writers, in-so-far as I am informed, have failed to furnish us with a record of the actual internal relations existing between the factors involved, freed of conventional and restricting assumptions.

With the assistance of Mr. W. N. Motter and Mr. S. R. Fox, I have carried on a series of experiments in the electrical laboratories of Purdue University for the purpose of investigating the subject.

APPARATUS AND METHOD EMPLOYED.

The experiments which I shall describe were made upon a three-light Brush arc machine, fitted with the necessary exploring coils, collector rings and revolving contact-making device. The machine was selected on account of the peculiarities of its design. These were particularly valuable, as the end sought was to obtain results of an exaggerated nature in order that the factors entering into the problem could be brought into bold relief and thereby lend themselves to more ready investigation.

The core of the armature is of the ring type and is built up of laminated iron stampings, held together by laminated iron bands passing around the core between the successive layers of stampings. Each stamping, therefore, forms a portion of the surface of a cylinder having its axis coincident with the axis of rotation. The stampings are shaped so as to make sixteen large teeth of trapezoidal section, which project laterally from the core, there being eight on each side. The armature winding is composed of eight coils or bobbins of 286 turns each. The bobbins on opposite sides of the armature are connected in series, and their free ends brought out to one pair of the eight commutator segments. Previous to making the experiments, all of the copper commutator segments were removed, and two cast-iron collector rings substituted for them. Fig. 1 shows the machine with these in position, and the collecting brushes in place. Each ring was connected electrically to one of a pair of commutator segment terminals, to which the free ends of one pair of the armature bobbins were fastened. The rings were then carefully insulated from contact with all the other commutator terminals. As the

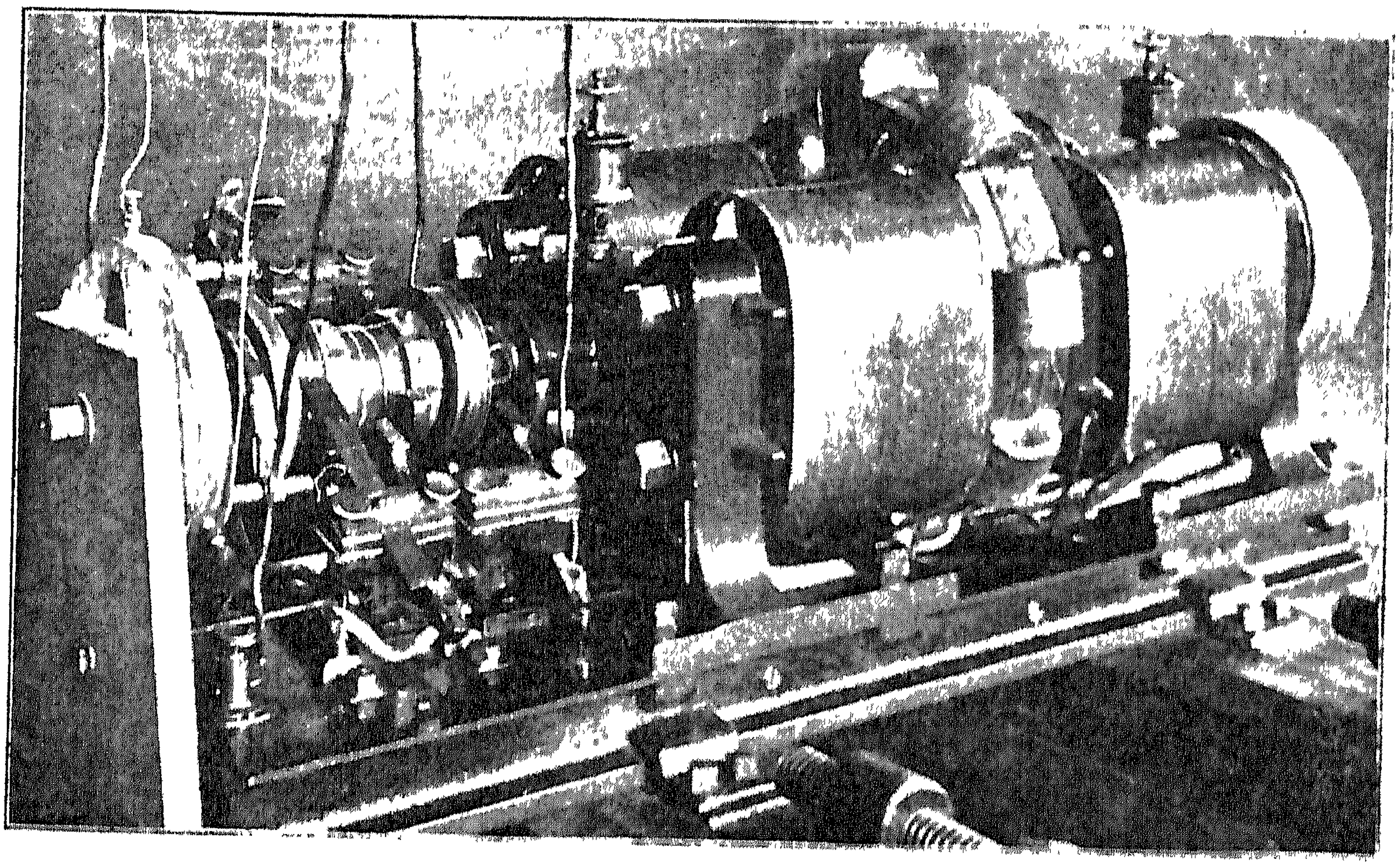

FIG. 1.

armature is of the open coil type, each commutator segment is attached to the terminal of but one coil, and therefore, by the arrangement described, the arc machine was converted into a two-coil alternator. Throughout the test, the remaining six coils were practically dead, being cut out and left on open circuit.

Owing to the fact that the armature bobbins are wound between large projecting teeth, and since the clearance spaces between the teeth and the pole-faces are relatively small, the inductance of the coils is high. The coils are practically buried in iron, and the leakage of the magnetic lines of force set up in them is slight. There are in all, 16 teeth on the armature core, or 4 to each pole face. As the armature revolves, there are alternatively 3 and then 4 teeth opposite each pole-face The latter condition occurs when two of the coils take up positions midway between the pole corners, as for instance, coils 1 and 2 in Fig. 2. The former when four of the teeth reach positions midway between the pole corners N, S, and N′, S′. The reluctance of the path of the magnetic flux through the field frame and the armature core is therefore a variable quantity, and pulsates between its maximum and minimum values eight times during each revolution of the armature.

The four field exciting coils are connected in series in such a way as to form like magnetic poles facing one another, on the same side of the armature shaft. By this arrangement the lines of force entering the armature core from abutting pole-pieces repel one another and, dividing, penetrate the armature core above and below the shaft in a direction perpendicular to a vertical plane passed through the centre of rotation and parallel to the shaft. When the armature core is at rest, therefore, and the field coils separately excited, the field flux passing through any pair of armature coils will be a maximum when they are in positions 1, 2, Fig. 2, and will be zero when they are in positions 5, 6.

The method employed in making determinations of the self-induction of the armature was as follows:

An exploring coil of 42 turns of No. 36 B & S copper wire was wound over armature coil 1, and connected in series with the field coils of a high-resistance Nalder ballistic galvanometer and an adjustable non-inductive resistance. A constant exciting current of 10 amperes was kept flowing through the field circuit at all times. During the time of taking any one set of readings, a direct current of definite value was maintained in coils 1 and 2 except when the deflections were made. In circuit with the two armature coils and the source of power, were connected a Weston ammeter, the primary of the calibrating coil of the ballistic galvanometer and a snap switch. The snap switch being actuated by a spring, gave exactly the same form of mechanical "make" and "break" of the current at each reading. Readings were taken when making and when breaking the current in the armature coils, and the average of four observations made a record for a given angular position of the coils.

The angular position of the coils relative to the poles was indicated by the graduated disk of the contact-making device by

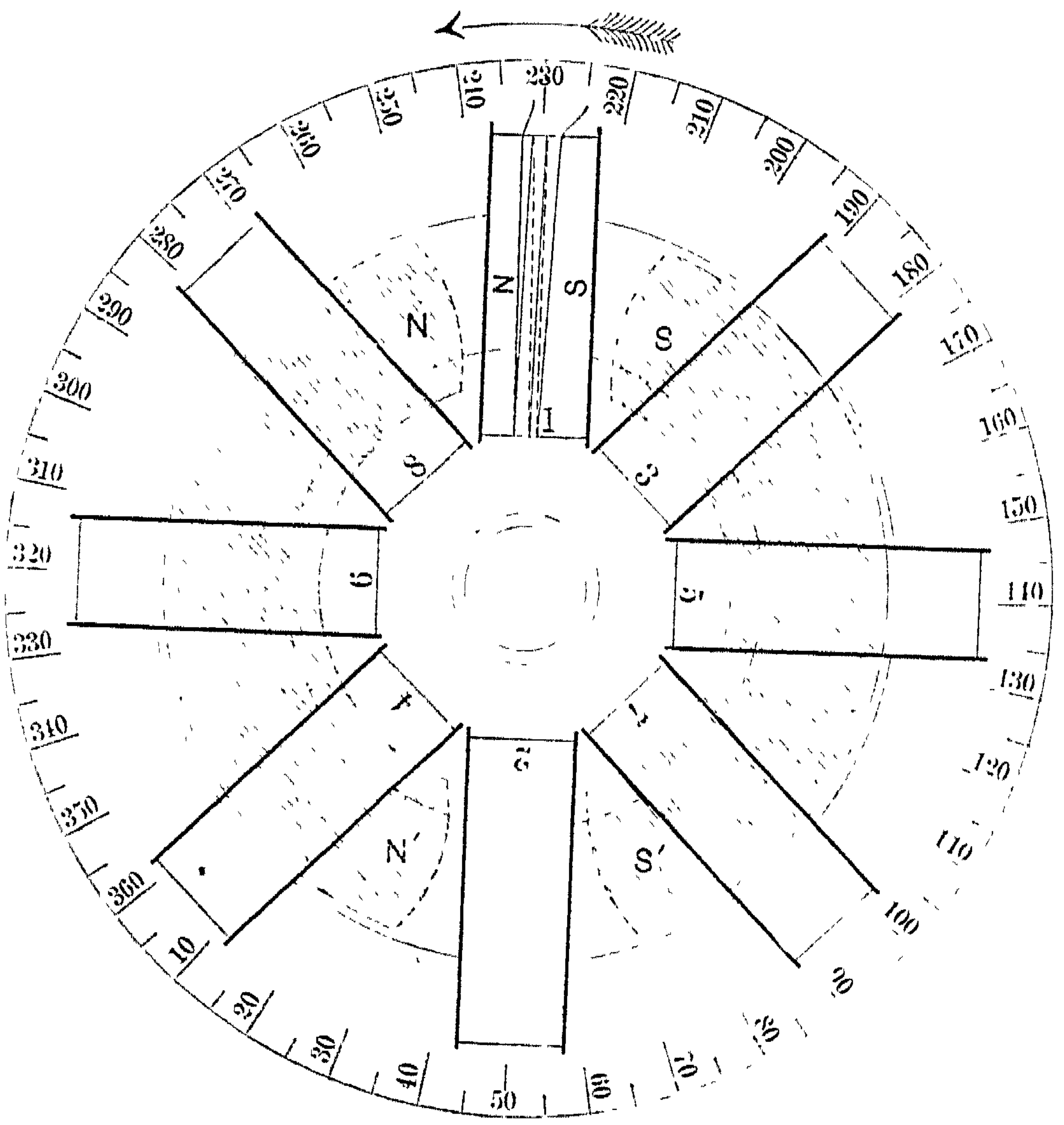

FIG. 2.—Showing coils No. 1 and 2 at "Zero Position" between the Pole Tips N, S, and N', S'.

adjusting it relatively to a point on the contact wheel at the time of taking each reading. Knowing the deflections of the galvanometer and having complete data covering the calibration of the instrument and the construction of the armature, the inductance of the coils at any given point was very readily calculated.

In determining the form of the electromotive force waves induced in the coils and appearing at the brushes of the machine, a form of contact-making device shown in Fig. 1 was used in connection with an improvised form of electro-dynamometer. The contact-making device possesses no new features. The galvanometer is of the Wiedemann type. The bell-shaped magnet and copper damper were removed from the instrument, and in place of these a wooden ball carrying a coil of fine wire imbedded in a deep narrow groove cut into its surface was substituted. Two pieces of copper wire were mounted upon the ball or needle in the plane of the coil, and at the extremities of a diameter to form an axis of rotation. The upper end of this axis made one terminal of the coil, it carried a small plane mirror and was connected at its extremity to a piece of hard-drawn brass wire. This wire being also attached to the torsion head, both sustained the weight of the ball and balanced by its torsion the deflecting force of the current impulses passed through the needle. The lower end of the axis formed the other terminal of the coil and carried a small paddle. It dipped into a cup containing mercury and glycerine: the glycerine sufficing to dampen the needle and the mercury making electric contact with it. When in use, the field coils of the galvanometer were excited with a constant current. The ball or needle was connected directly in series with the rotary contact, and with from two to three incandescent lamps, according to the value of voltage to be measured. The instrument was calibrated by connecting a constant current machine in series with the needle, lamps and rotary contact, and comparing the deflections of the needle taken while the contact was rotating at normal speed, with the readings of a voltmeter connected to the terminals of the source of constant E. M. F. During all the experiments, the galvanometer gave deflections as constant and as dead beat as those of a Weston ammeter. The arrangement of this apparatus is analogous to that described by Duncan[1] in 1892.

ARMATURE INDUCTANCE.

In determining the coefficient of self-induction of coils 1 and 2, coil 1 of the armature was placed at the 230° position, as indicated in Fig. 2, since at this point the magnetizing power of the coils was least, owing to the large magnetic reluctance of the circuit traversed by the lines of force emanating from the coils. The high reluctance is due to the fact that the iron of the core surrounded by the coils, and the iron of the pole tips N, N′ and S, S′, is all highly saturated by the field flux, and to the fact that the lines of force set up by the coils must either span an air-gap many times larger than the clearance space, or else pass through the entire field circuit of the machine.

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[1] Duncan, "Note on some Experiments with Alternating Currents." TRANSACTIONS, vol. ix, p. 79.

When in the 230° position and with a constant current of ten amperes flowing in the field circuit, and a constant current of 4.3 amperes flowing in coils 1 and 2, the ballistic galvanometer gave a deflection of 25 both at the "make" and at the "break" of the current. The current in the coils at this time was flowing in the same direction as that in which the alternating current is flowing when the coils are passing out from under the pole tips, and the armature is rotating in the normal counter-clock-wise direction. From position 230° the coils were moved in a clockwise direction, as viewed from the commutator end. This is opposite to the direction of rotation of the armature when running, but in the same direction as that in which the rotary contact brush was moved when the E. M. F. curves were taken. At the 220° position, "make" and "break" readings both equal to 24 were obtained. At position 210° the readings gave 25 divisions again. At 200° they were all 30 divisions, and so on through one-half of a revolution of the armature. When plotted, these readings gave the curve A of Plate 1.

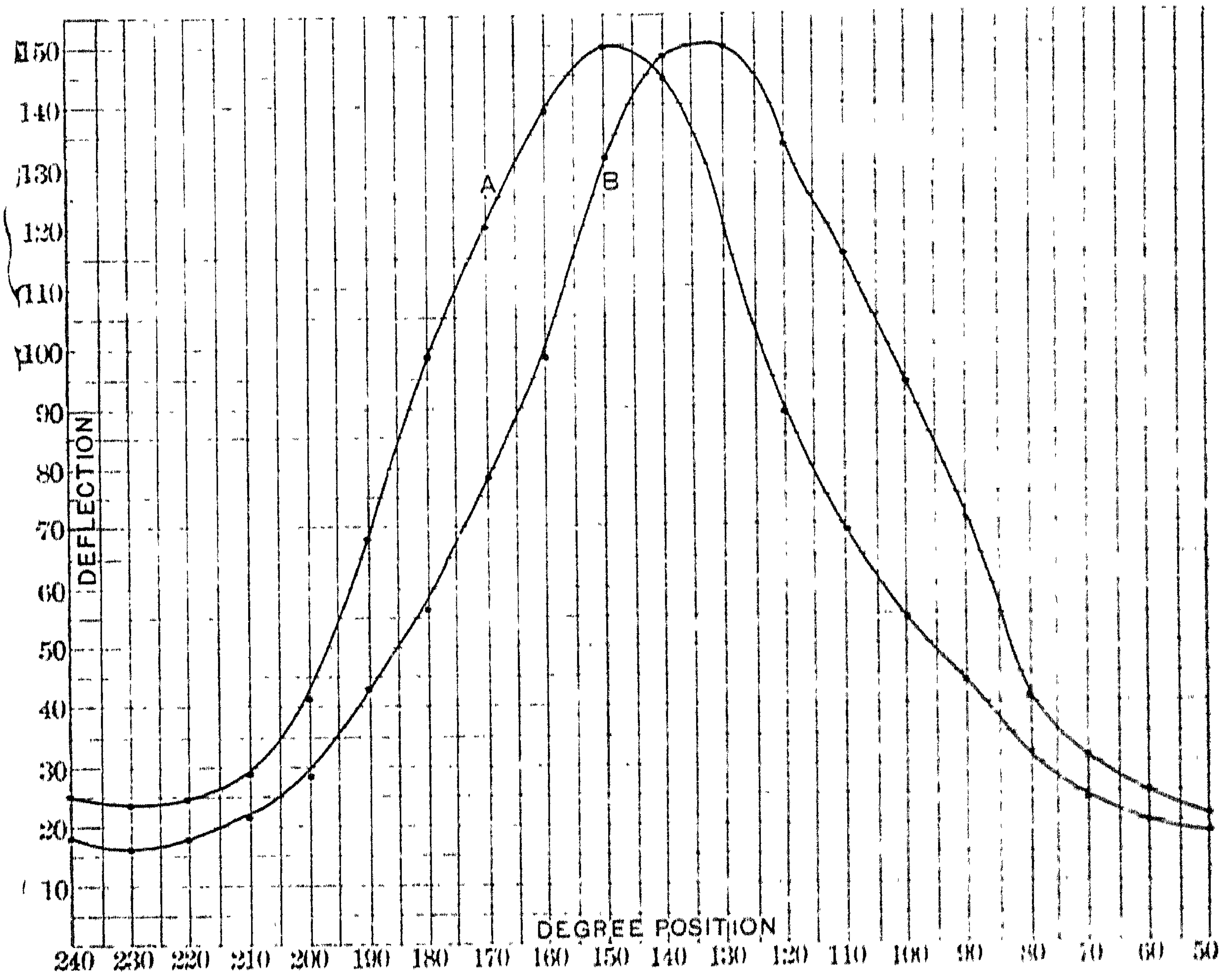

PLATE 1.

An inspection of this curve shows that it is distorted in the direction of the normal rotation of the armature. Thinking that its unsymmetrical form might not be entirely due to a magnetic reaction between the armature and fields, and that possibly it was caused, in part at least, by a variation in the width of the air-gap space, owing to the core of the armature not being quite true, the curve was continued through the complete revolution. The result of the test, however, gave another curve exactly like curve A. This indicated conclusively that lack of symmetry in the mechanical construction of the machine played no part in causing the distortion. The current in the coils 1 and 2 was then reversed in its direction while being kept at the same volume. The exploration resulted this time in giving the curve B, of Plate 1. As before, the "make" and "break" gave the same deflection for any given position, but the curve was found to be drawn over towards pole tips S′ and N, Fig. 2, instead of towards S and N′, as in the case of curve A.

The distortion of these curves, the ordinates of which are proportional to the inductance of the coils in various angular positions, is entirely due to the variation of the permeability of the iron composing the armature core and pole-faces, as the energized armature coils are moved through the half revolution. When curve A, Plate 1, was taken, the current passing through the coils tended to produce a magnetic field in opposition to that induced by the field circuit when the coils were in the 185° position, and one aiding the field flux when they were in the 95° position. In other words, poles were generated in the coils as indicated by the small N and S on coil 1 of Fig. 2. With the coils in the 95° position, when the circuit was made, a number of ampere turns were brought into action, which increased the induction in the surrounding masses of iron and at the same time decreased their permeability. With the coils in the 185° position, making the circuit through the armature, decreased the magnetic density in the surrounding iron and thereby increased its permeability. Breaking the armature circuit in either case brought the induction back to the same initial value, since the two positions assumed are symmetrically located relatively to the pole-faces. The introduction of the same magnetizing force into the coils, however, did not cause the same variation in the induction threading the coils. Since the variation in the value of the permeability is in opposite directions in the two cases, the variation in the flux in the 185° position is greater than that which occurs in the 95° position, and therefore the self-induction of the coils in the former is greater than in the latter, under the assumed conditions.

Magnetic hysteresis also plays a part in the variability of the armature inductance. As the armature revolves, the iron of the core passes through a complete hysteretic cycle once every revolution, and in making determinations of the armature inductance, account must be taken of the fact that the magnetization of the iron of the core follows the perimeter of the loop of hysteresis and not the "B and H curve," as the permeance of the core changes.

To determine the extent of the error introduced by neglecting to adhere to the true magnetic changes through which the iron passes, as is the case in the method so far described, a rather laborious process had to be resorted to of carrying the iron in the core completely through the hysteretic cycle before taking each reading. By this means, owing to the fact that when a coil is between the pole tips, the laminated core of the coil is highly saturated, it was possible to get a very fair estimate of the influence of hysteresis.

Suppose we take the hysteresis loop of Fig. 3 to represent the cycle through which the magnetization of the iron passes during a revolution of the armature. Let *a* represent the magnetic density in the core of coil 1 when it is in 230° position, and no current flowing in the coil. As the armature is revolved in a counter-clock-wise direction, the intensity of the magnetization in the core will decrease until at the 320° position it will have a value equal to *o*, *b*. At some point farther on, say at 330°, there will be a sufficient negative force to reduce the residual magnetism to zero, as at *c*, Fig. 3; and finally, when coil 1 reaches the 50° position, the magnetism will have been brought up to a negative maximum within the coil, as at *d*. If at this point the circuit is made through the armature coils, and a constant current sent through them in the direction which aids the field flux, the density in the core will be increased to a still higher value, and rise up to *e*. Suppose now that the armature is revolved still further round, for instance, to the 120° position. The flux penetrating the coil will diminish to *f*. If at this point the armature current is broken by the snap switch, a current impulse will pass to the galvanometer needle from the exploring coil, due to the decrease in the induction threading the coil from *f* to *g*. If, without changing the position of the coil, the current is made again, the density will rise to *h*, but will not come up to the original value at *f*. In other words, any number of "makes" and "breaks" can be made after the first "break" with the same result, but the first "break" will give a larger reading than the others. The first "break" gives the most accurate result. By this method, however, coil 1 has to be brought back to the 230° position before taking each reading, then revolved counter-clock-wise to the 5 t position, and, after the current is made, has finally to be moved to a position between s′ and s, to take the reading at the "break."

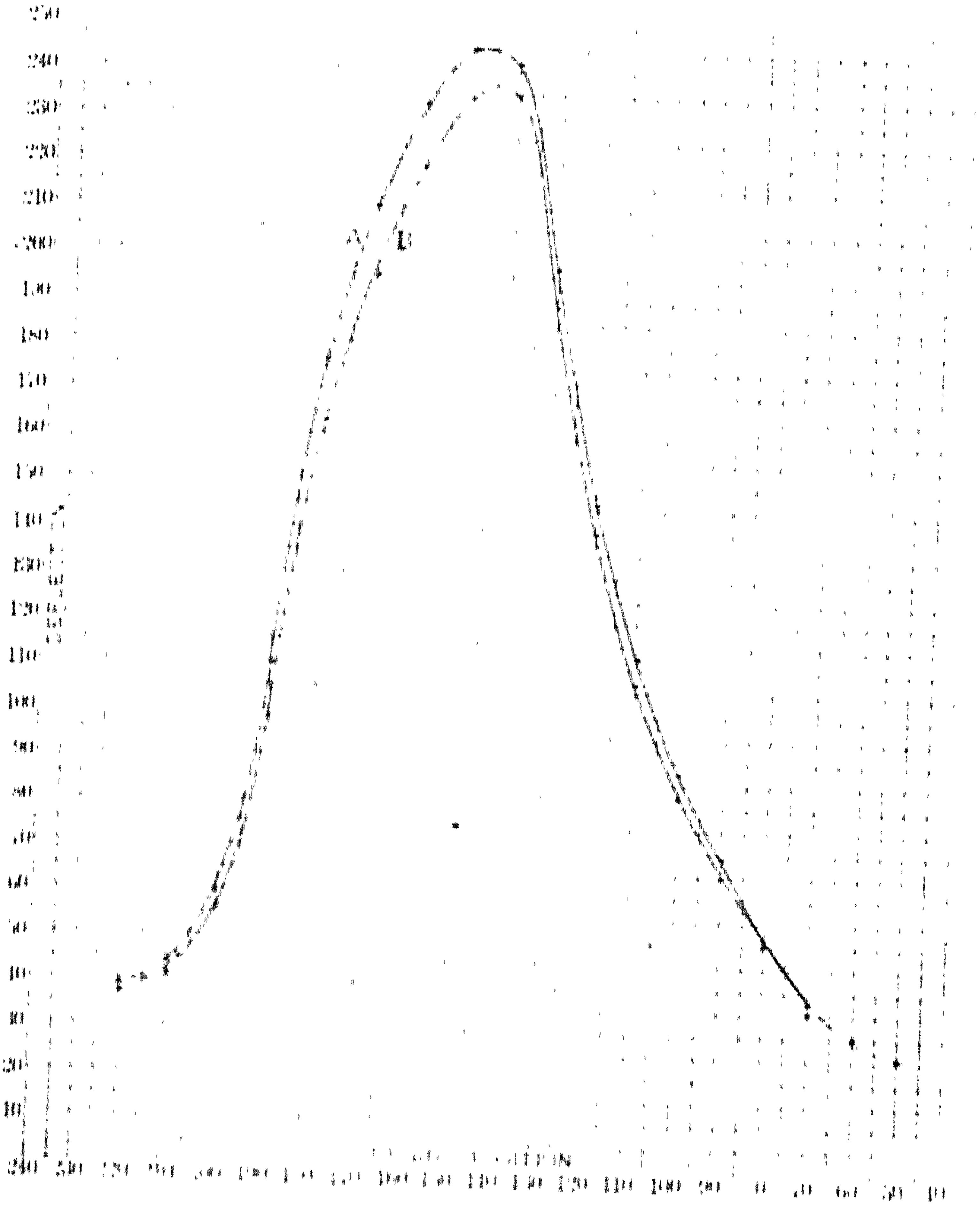

PLATE 2.

Following out this method for one set of readings, curve A, of Plate 2, was obtained. Curve B is a curve plotted from an average of the readings due to the second and third "breaks" and their corresponding "makes." It is identical with a curve taken by the method used in obtaining curves A and B, of Plate 1, but with the same armature current as that used in obtaining the curve A of Plate 2. An inspection of the curves of Plate 2 shows that the maximum percentage variation occurs at the 190° position, where it amounts to 12 per cent., and that the maximum actual variation occurs at the 170° position, where it amounts to 15 divisions, or 7.8 per cent. of the deflection at this point. This represents an actual difference of .0117 henrys at the 170° position.

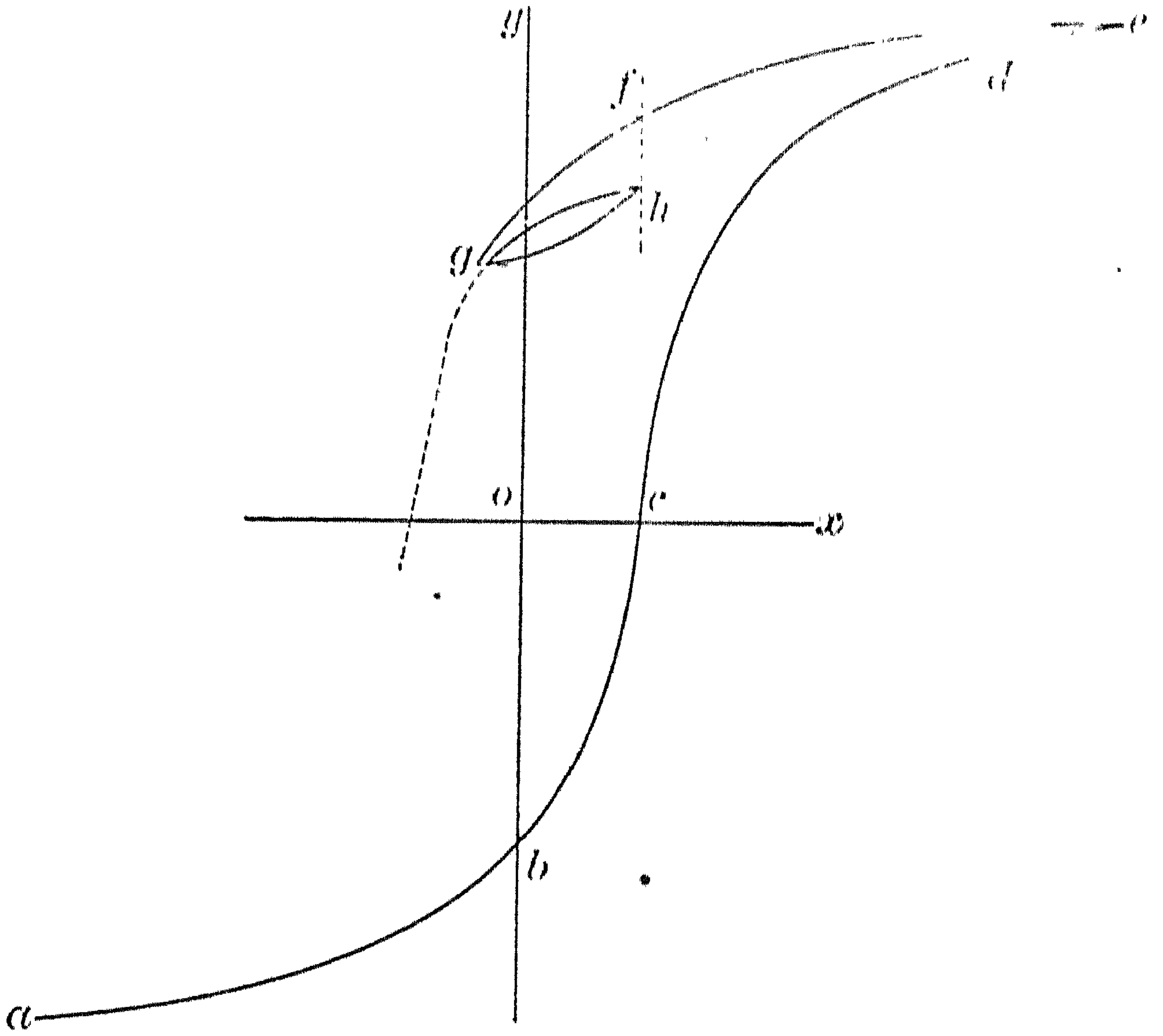

FIG. 3.

As was to be expected, from the considerations outlined above, the curve A of Plate 2 shows a greater distortion in the direction of rotation than does the curve B, taken by the less exact method. It reaches a maximum later in the cycle, and although of uniformly greater amplitude than curve B, the differences are most marked in the last half of the cycle, counting time from right to left.

Curves A and B are, however, exactly similar in form and so nearly alike, that it was not deemed necessary to follow out the more elaborate and exact method in succeeding determinations of the variable inductance, as the end in view was to determine the character of the changes occurring, rather than the absolute value of them.

Plate 3 exhibits a series of these inductance curves. They represent five explorations, made with direct currents of different intensities flowing through coils 1 and 2, while the field exciting current was maintained constant at 10 amperes, as usual. The readings have been reduced to henrys; the calculation of the values being based upon the supposition that the inductance of the two coils at any point is proportional to the change in the number of lines of force existing in the coils at that point, divided by the current flowing in the coils and producing the change. The plotted values, therefore, represent the inductances of the two coils in series, proper allowance having been made for the fact that the exploring coil was only wound about one of them.

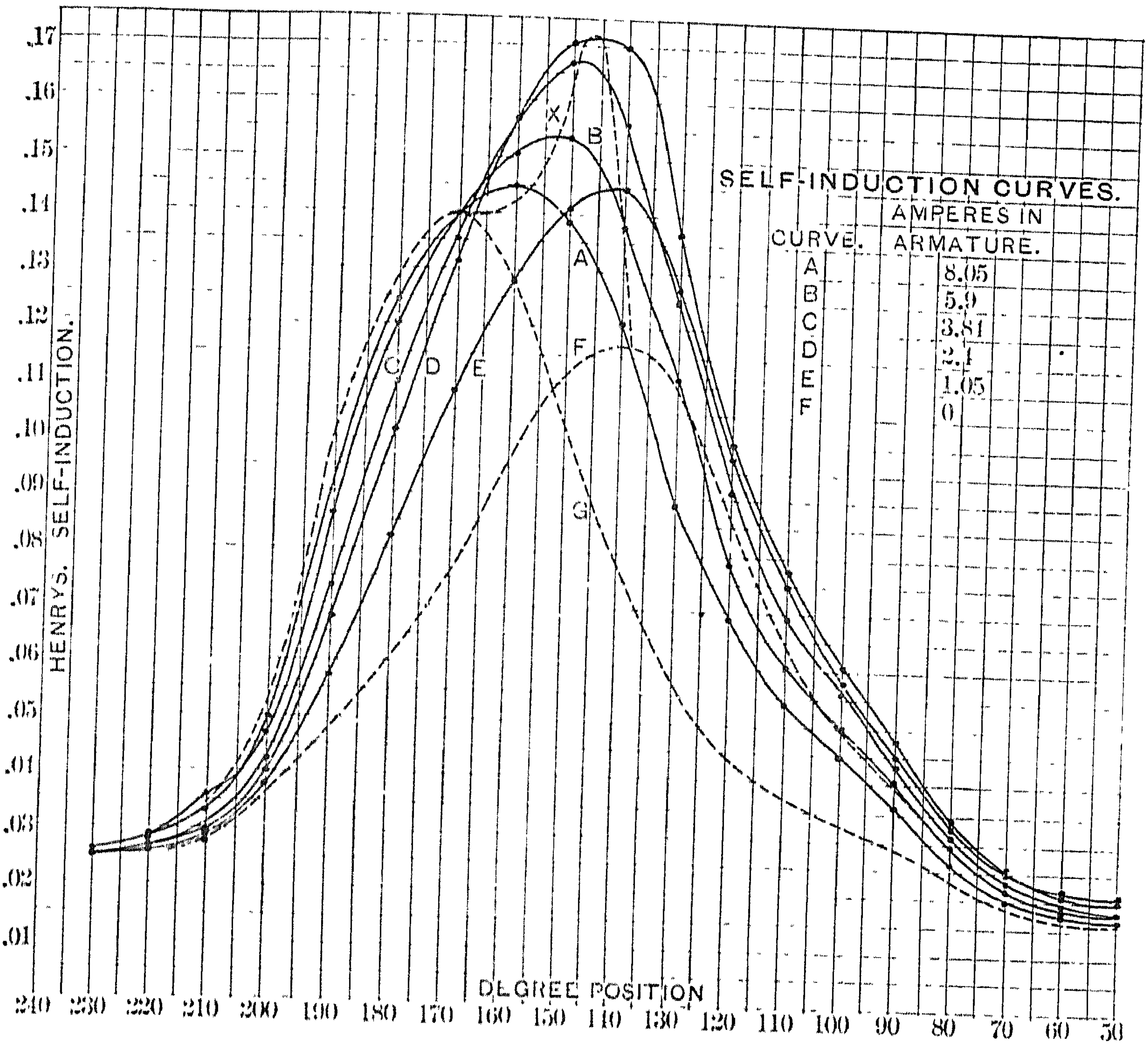

PLATE 3.

The curves of Plates 4 and 5 have been derived from those of

Plate 3. They show the relation between the direct currents flowing in the coils and the inductance of the coils, and are useful when it is desired to determine the curve of instantaneous inductance that corresponds to a given alternating current wave.

The curves of Plates 3, 4 and 5 bring to light some very interesting facts. They show that the maximum coefficient of self-induction occurs when the coils are in the 145° position and the current flowing in them has a value of 2.5 amperes; under these conditions their inductance is over .172 henrys. They indicate that as the armature current is varied from zero up to its maximum safe value, the inductance of the coils undergoes very marked and relatively rapid changes. The dotted curve F has been plotted from the ordinates of the curves on Plates 4 and 5 that correspond to the zero value of current. It represents the initial inductance cycle, and is the basic curve to either side of which the inductance curves for the various currents fluctuate. Curve F is practically symmetrical relatively to the pole-faces. Its crest occurs as the coils pass the centre of the pole-faces, and it slopes equally on either side. The line x, drawn from its crest through the crests of the other curves, indicates the successive positions and values assumed by the maximum inductance cor-

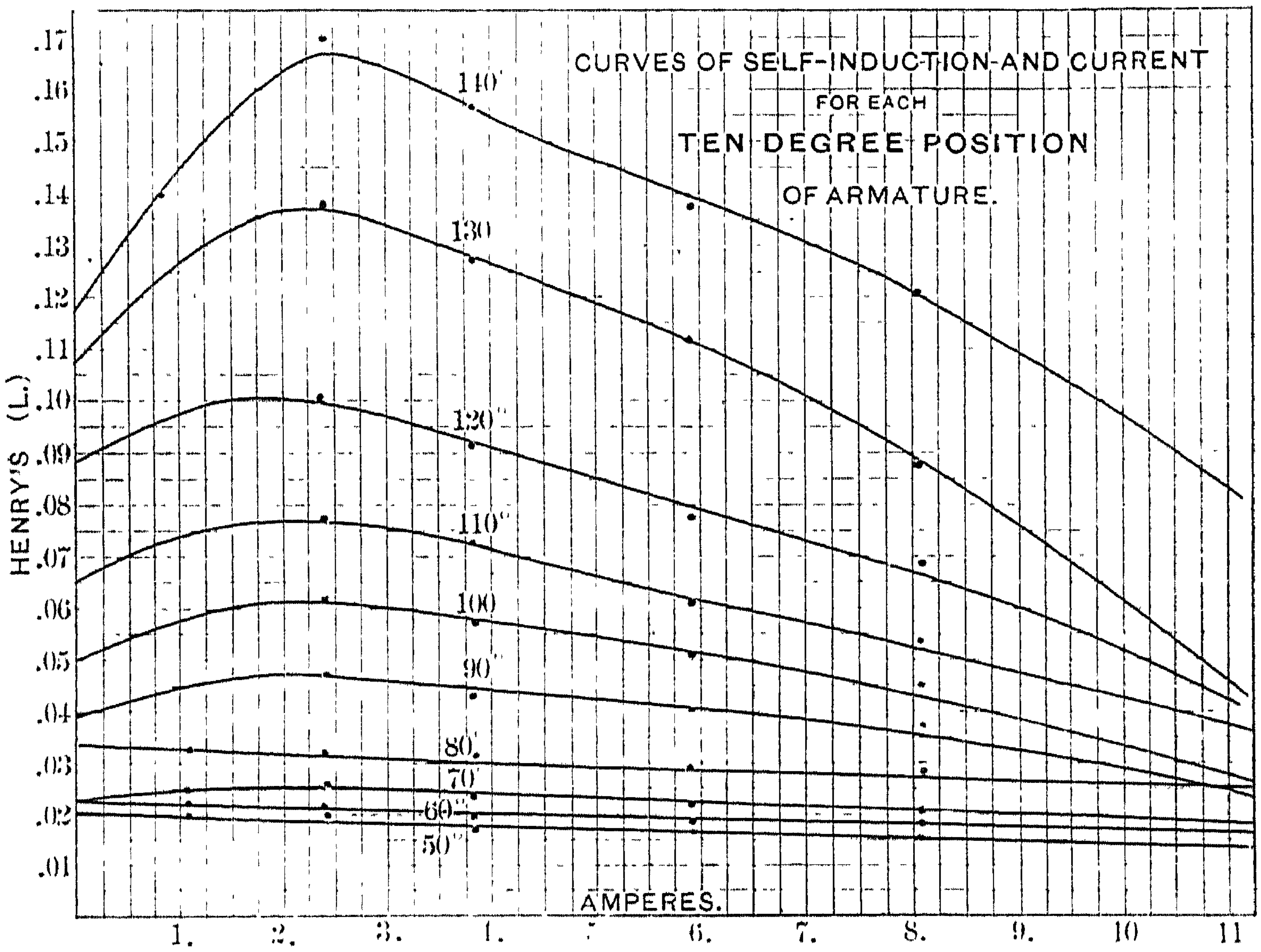

PLATE 4.

responding to different constant currents, as the volume of these currents is increased from zero. The maximum current-carrying capacity of the armature is 15 amperes, but the inductance is changed from its maximum initial value of .117 henrys to its maximum possible value of .172 henrys when the armature current reaches 2.5 amperes. Any further increase in the current causes the amplitude of the inductance wave to diminish, and at 8 amperes it is only 85 per cent. of what it is at 2.5 amperes.

Besides varying in amplitude, the inductance waves undergo a lateral shifting in the direction of the rotation of the armature.

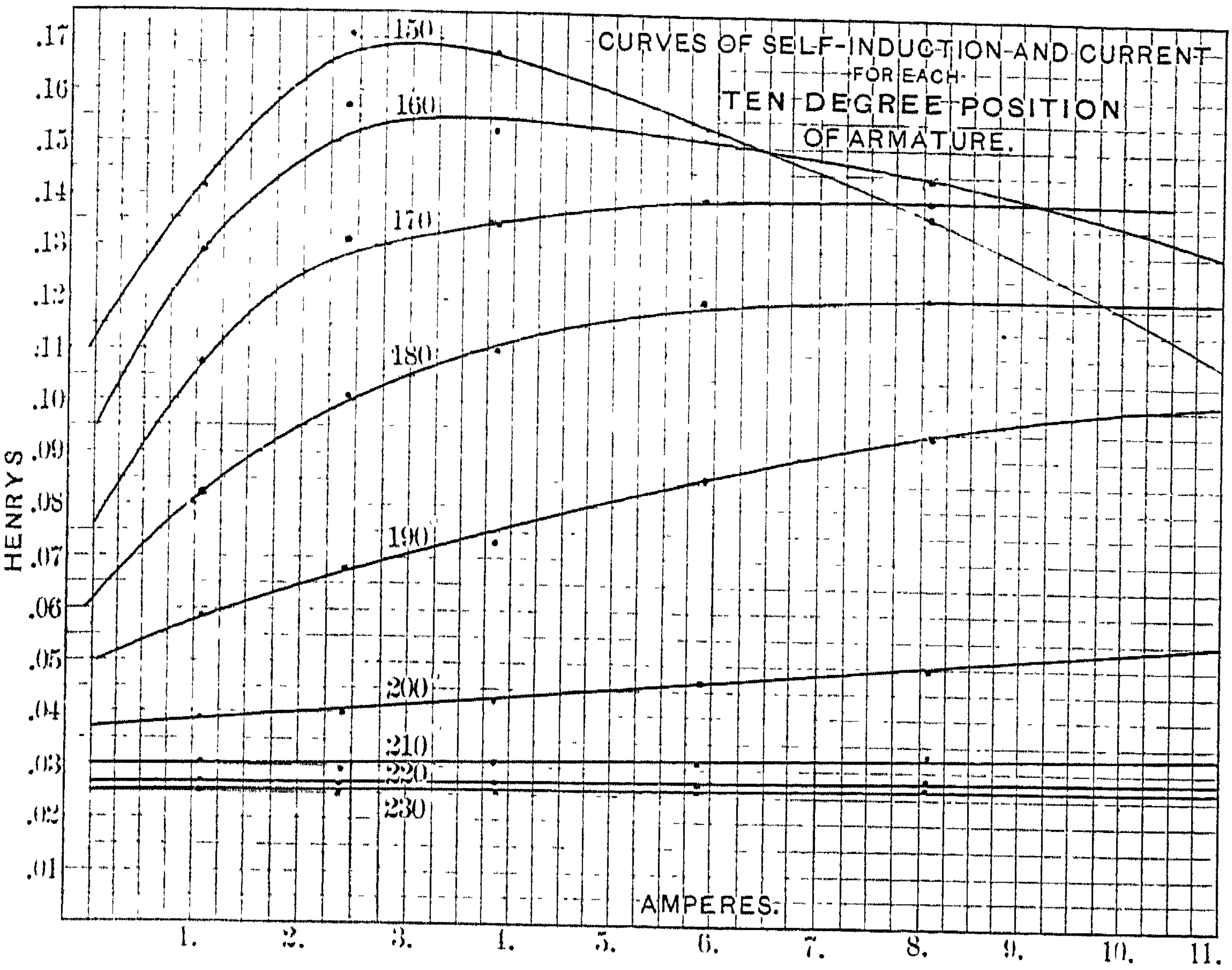

PLATE 5.

The dotted curve *a* has been taken from Plates 4 and 5, and represents the inductance curve corresponding to 11 amperes. An inspection of Plate 5 shows that this curve practically marks the limit of the variability of the inductance. For a further increase in the current, the 170° curve of Plate 5, tends to remain horizontal, and the 180° curve exhibits no disposition to rise appreciably beyond the 11-ampere point, there will therefore be practically no further shifting of the crest, or change in the amplitude of the induction curve.

To better appreciate the extent of the distortion that occurs, it is well to note that at the 170° position there is a difference of about .065 of a henry between curves A and F of Plate 3, showing that the inductance of the coils at this point has double the value at full load that it has at no load. This fact is brought out strongly in Fig. 4, which shows the differences between the ordinates of curves D, F and G. In this figure, the amounts by which the ordinates of curves D and G of Plate 3 differ from those of curve F have been plotted as ordinates relatively to curve F reduced to a horizontal base line.

It is also interesting to note that between no load and full load, the crest of the induction curve moves through an angle of 30°, or over one fourth of the width of the pole-faces.

The fluctuations which take place in the armature inductance, are due to the changes occurring in the reluctance of the path traversed by the flux induced by the armature current. The action of the armature current is to intensify the induction in the armature core between the 60° and 130° positions of coil 1. The initial induction in the core was over 24,000 gausses when the coils were between the pole tips. The armature current acting with the field excitation maintained this saturation during the first part of the revolution and prevented any great variation in the induction in the first quadrant. But during the second and fourth quarters of each revolution, when the coils were between the 170° and the 200° positions, the armature current was reacting against the field excitation, and thereby, by diminishing the flux density, was increasing the permeance of the iron and

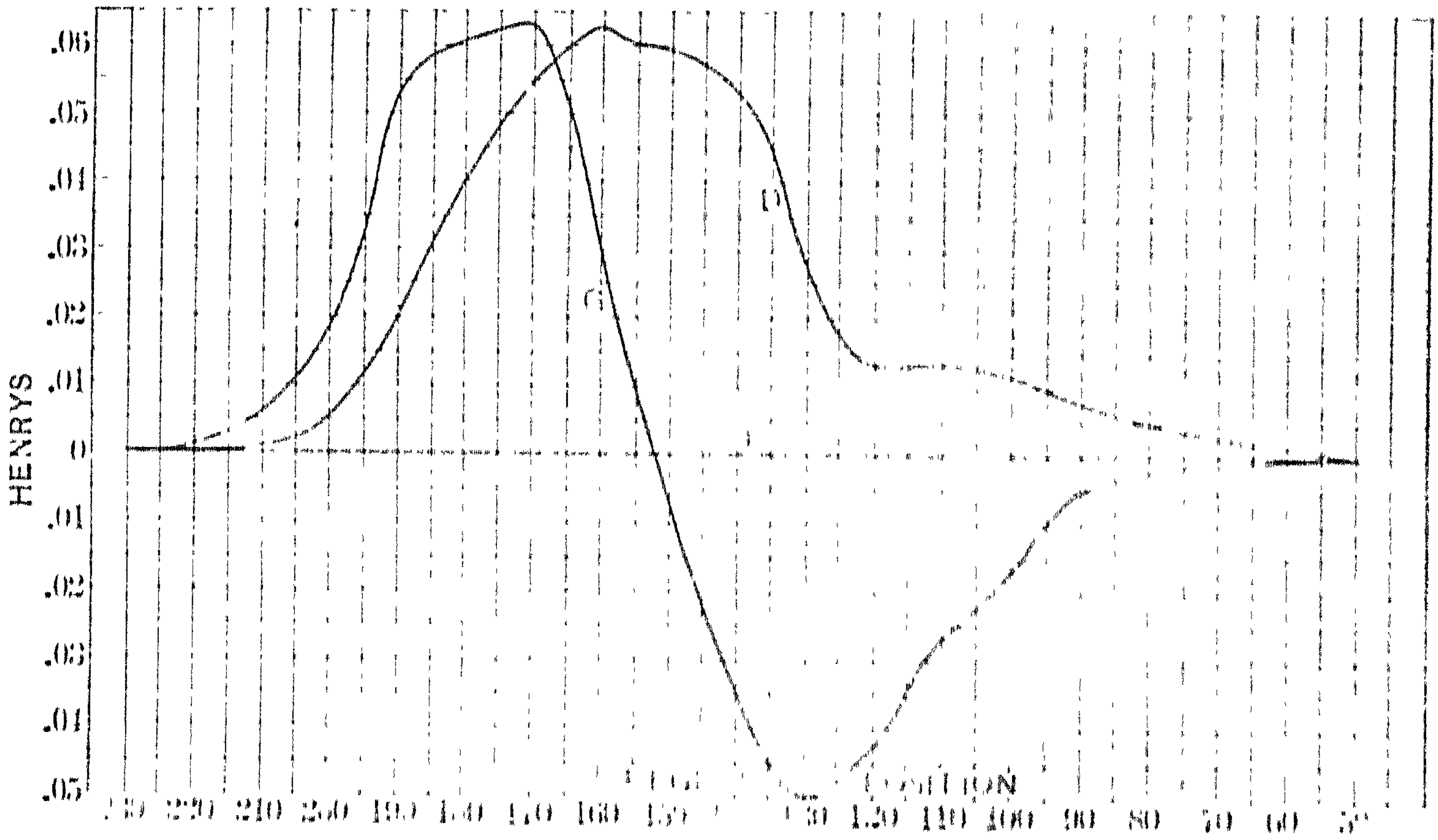

FIG. 4.

the inductance of the coils for these positions. The magnetizing power of the coils is considerable, as with 8 amperes flowing through them, they set up an induction of 18,000 gausses in the core when in the 160° position.

The great amplitude of the induction wave for 2.4 amperes in the coils is in the same way due to the fact that the permeance of the path is least when the magnetizing force is that due to this current. If we plot the values of the 140° curve of Plate 4 in terms of the armature current and the induction set up in the core by the current, we obtain the curve shown in Fig. 5. This is "B and H" curve for the magnetic circuit through the armature core in this position, and the point T which corresponds to the maximum ordinate of the 140° curve, is the point where a tangent to the curve makes the greatest angle with the base line.

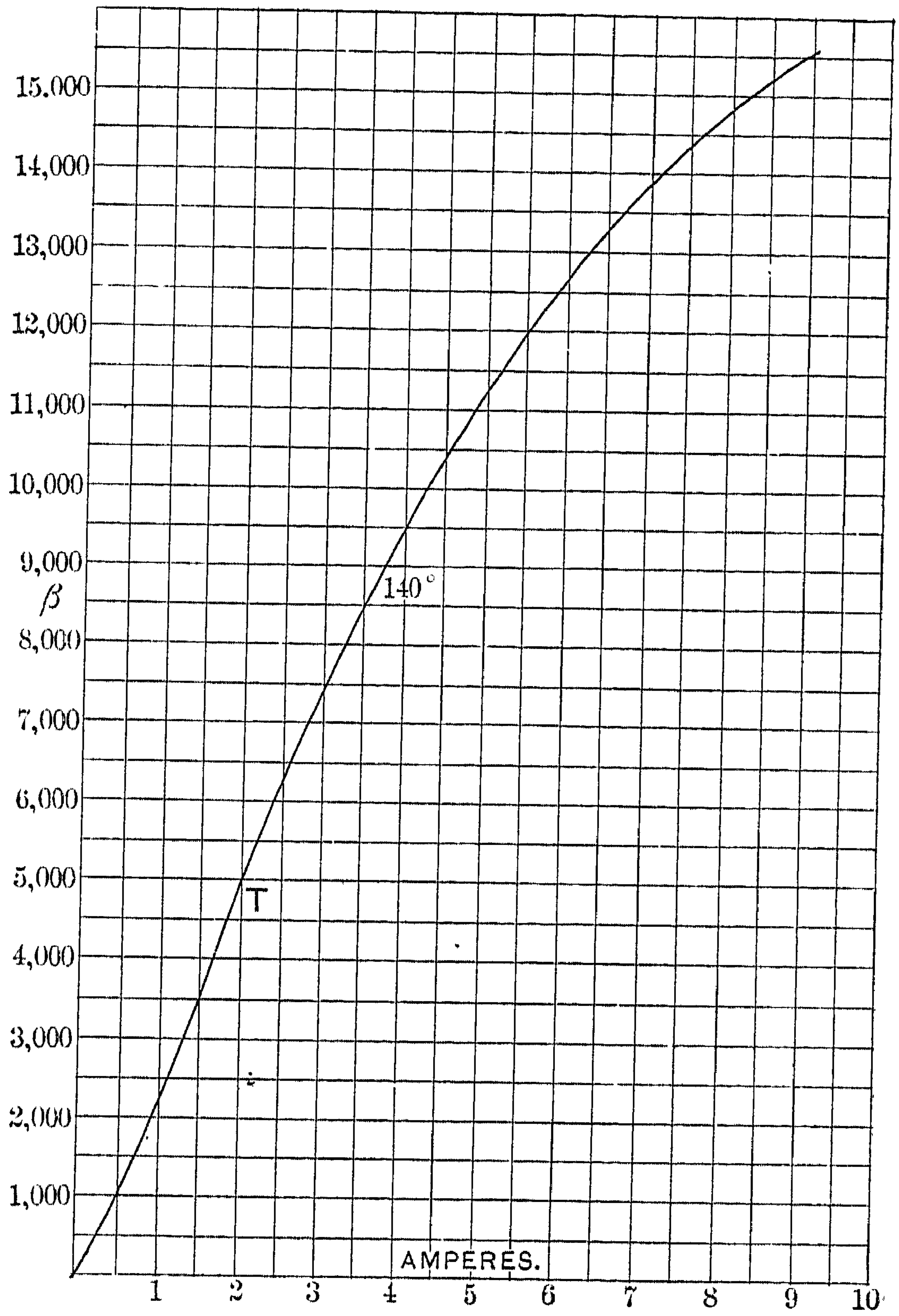

Fig. 5.

The large teeth of the armature core do not seem to have the effect of causing any marked irregularities in the inductance curves. It is noticeable, however, that there is a slight hump in all of them at the 90° position. This is caused when the teeth immediately behind the coils pass the pole tips. The same effect is produced by the other teeth, but it is too slight to appreciably affect the readings.

ELECTROMOTIVE FORCE CURVES.

A series of electromotive force curves taken from the machine are shown in Plate 6. These illustrate the gradual change in the wave form of the effective electromotive force as the load increases. By the effective electromotive force is meant the electromotive force that is in phase with the current and overcomes the ohmic resistance.

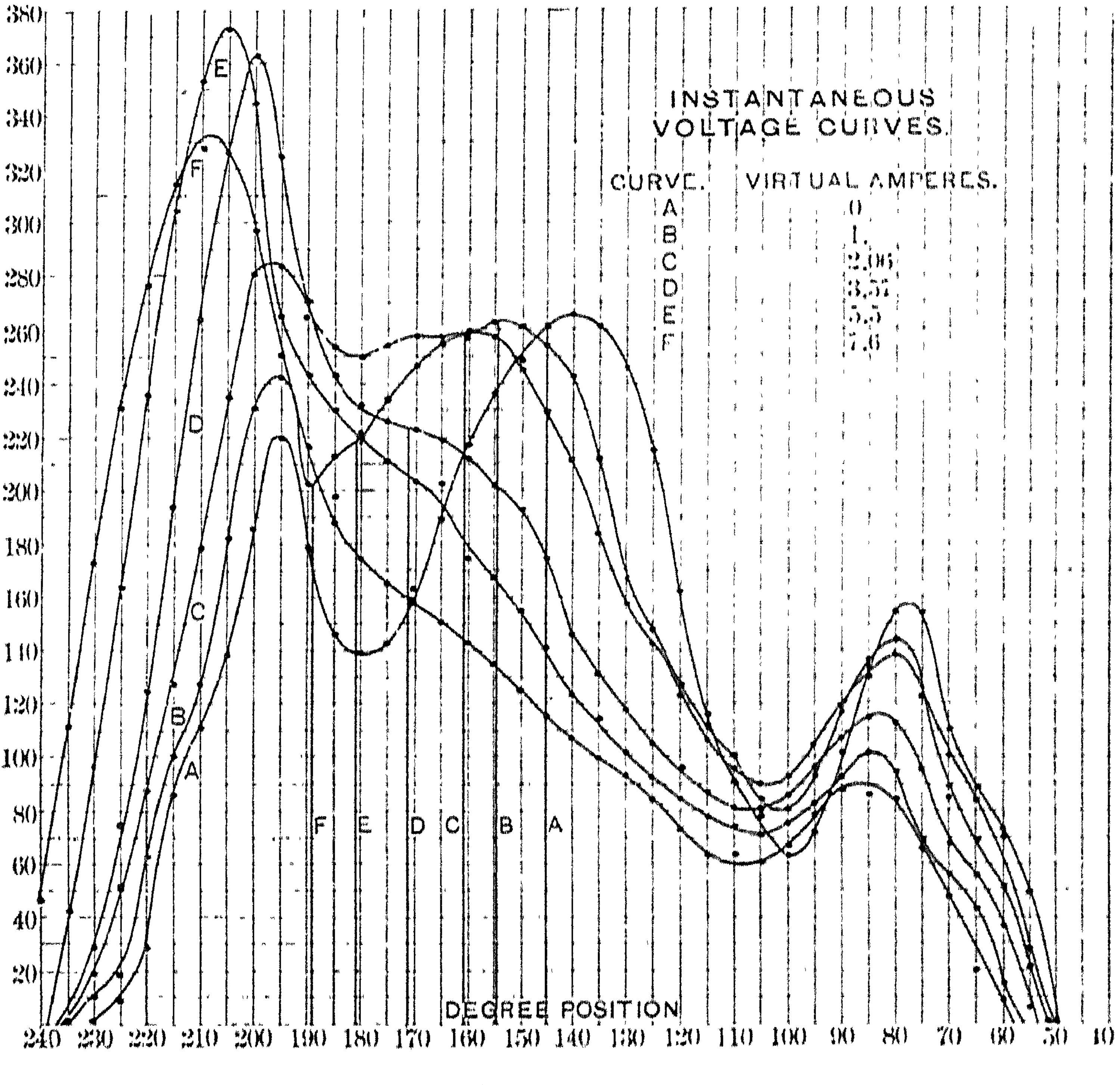

PLATE 6.

There is quite an appreciable lag in the effective electromotive force for the higher loads, owing to the armature inductance. This can hardly be regarded in the light of a simple phase displacement, as the lag partakes largely of the nature of a transformation of the fundamental wave A, that is due to the phase positions of the higher harmonics being shifted relatively to the fundamental harmonic, and not to any material change in the phase position of the fundamental harmonic itself. The extent of the shifting is best appreciated by noting the positions of the ordinates A, B, C, D, E and F. These lines bisect the areas of the electromotive force curves designated by corresponding letters, and indicate the points at which the induction threading the coils passes through zero and changes sign.

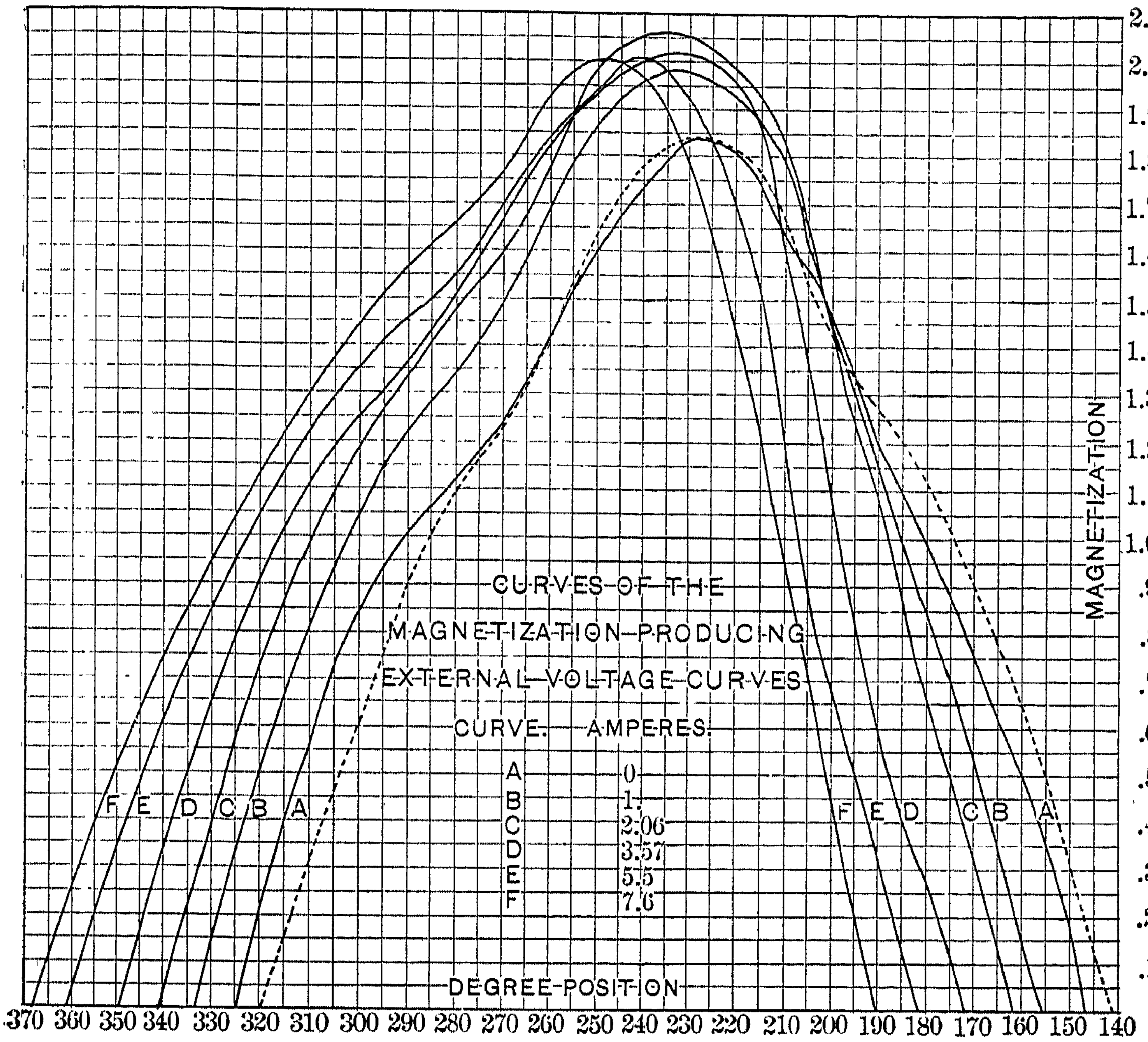

PLATE 7.

The curves of Plate 7 have been determined from those of Plate 6 by integrating the areas of the latter. They illustrate the waves of magnetism producing the effective electromotive force curves, and give a better idea of the extent of the lag that takes place. The scale of ordinates of Plate 7 expresses the value of the integral,

$$\int e\, dt = -N, \tag{1}$$

as determined from the curves of Plate 6, and must be multiplied by the constant 12206 to express the value of the induction per sq. cm. in the iron of the armature core. The maximum induction occurring in the core is therefore a little over 25,000 gausses.[1] In determining the value of the constant, an allowance of 20 per cent. was made for the lamination of the iron, 80 per cent. of the gross area of the core being used as the equivalent of the iron.

Curve A of Plate 6 was obtained with zero current in the armature. This is the "fundamental" or internal electromotive force wave of the machine. It will be noticed that it is not symmetrical about the 140° ordinate. It is an irregular curve having three prominent peaks; the right hand one slightly depressed, the left hand one raised somewhat, and the central one practically symmetrical about the centre line of the pole-faces. The ear peaks are due to higher harmonics being superimposed upon the fundamental wave by the magnetic disturbances in the air-gap that are caused by the large teeth. Steinmetz[2] has noted this effect and treated the subject of the distorting influence of armature teeth in a masterly manner. His results indicate comparatively symmetrical waves for no-load conditions. In the case under consideration, a marked shifting of the electromotive force curve in direction of rotation is caused by the teeth immediately on each side of the coils. As the teeth approach the pole tips, the lines of force do not appear to reach out to receive them to any extent. There is a sluggishness apparent. On the other hand, when the teeth are leaving the trailing pole tips, the lines of force seem to hold on with tenacity, and when they do let go, fly back with a snap as would extended strands of elastic. In the extreme cases, this action does not appear to occur until the tooth is over an inch away from the pole tips. The rapid cutting of the lines necessarily augments the potential at this point.

This explanation has its bearing upon the case, but the distortion is perhaps better explained by looking at it in the light of the part played by hysteresis and eddy currents. The eddy currents induced in the pole tips tend to oppose any change that takes place in the field distribution of the induction. They help to maintain a high induction in the trailing pole tips, and keep down the induction in the leading pole tips. The iron in the core of the armature is being carried through a complete hysteretic cycle at each revolution. The iron in the pole tips is carried through an hysteretic loop with the passage of each tooth across the pole-face. At the leading pole tips, the magnetism in the core iron is always working on the descending portion of the curve of hysteresis, and the reluctance of the magnetic circuit by the leading pole tips is increased accordingly. At the trailing pole tips the iron is worked on the ascending side of the hysteretic curve, and the reluctance of the path by the trailing pole tips is thereby reduced. The same magnetizing force, therefore, acting upon the two paths, induces a distorted field when the armature is running, and a symmetrical field when the armature is at rest, as shown by curve A and the dotted curve of Plate 7. The latter curve was obtained by exploring the air-gap distribution of the flux by the ballistic method, using the exploring coil wound over coil 1, and breaking the field circuit.

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[1] Some elaborate tests were made on Brush dynamos in 1889, by Mr. Murry. The values of B attained were about 4,800 gausses in the field, and 27,000 in the armature cores. See S. P. Thompson's "Dynamo Electric Machinery," p. 464, 1892 edition.

[2] C. P. Steinmetz, TRANSACTIONS, vol. xii., p. 470.

The activity displayed by the eddy currents in heating up the pole tips is quite remarkable. The curves B and A of Plate 8 indicate the rise in temperature of the leading and trailing tips, respectively, throughout a two hours' run. The readings were taken from thermometers fastened directly to the pole-pieces. The curve C is a curve of differences derived from curves A and B, and it indicates how very much more rapidly than the temperature of the leading pole tips the temperature of the trailing pole tips rises during the first twenty minutes of the run. Their differences in temperature after that time is practically constant. The curves plainly indicate that much greater magnetic disturbances occur in the leading pole tips than at other points in the pole-faces. The thermometers had to be fastened to the back of the pole tips during the test; had it been possible to place them in contact with the air-gap face, more rapid changes would doubtless have been recorded. During the test the field coils were excited with a current of 10 amperes, and the armature was loaded to about 5 amperes. At the end of the run, the temperature of the armature was 42° C.

As the armature core has sixteen teeth, or four per pole face, we may expect harmonics as high as the ninth to play a prominent part in the wave structure.[1] The general form of the internal

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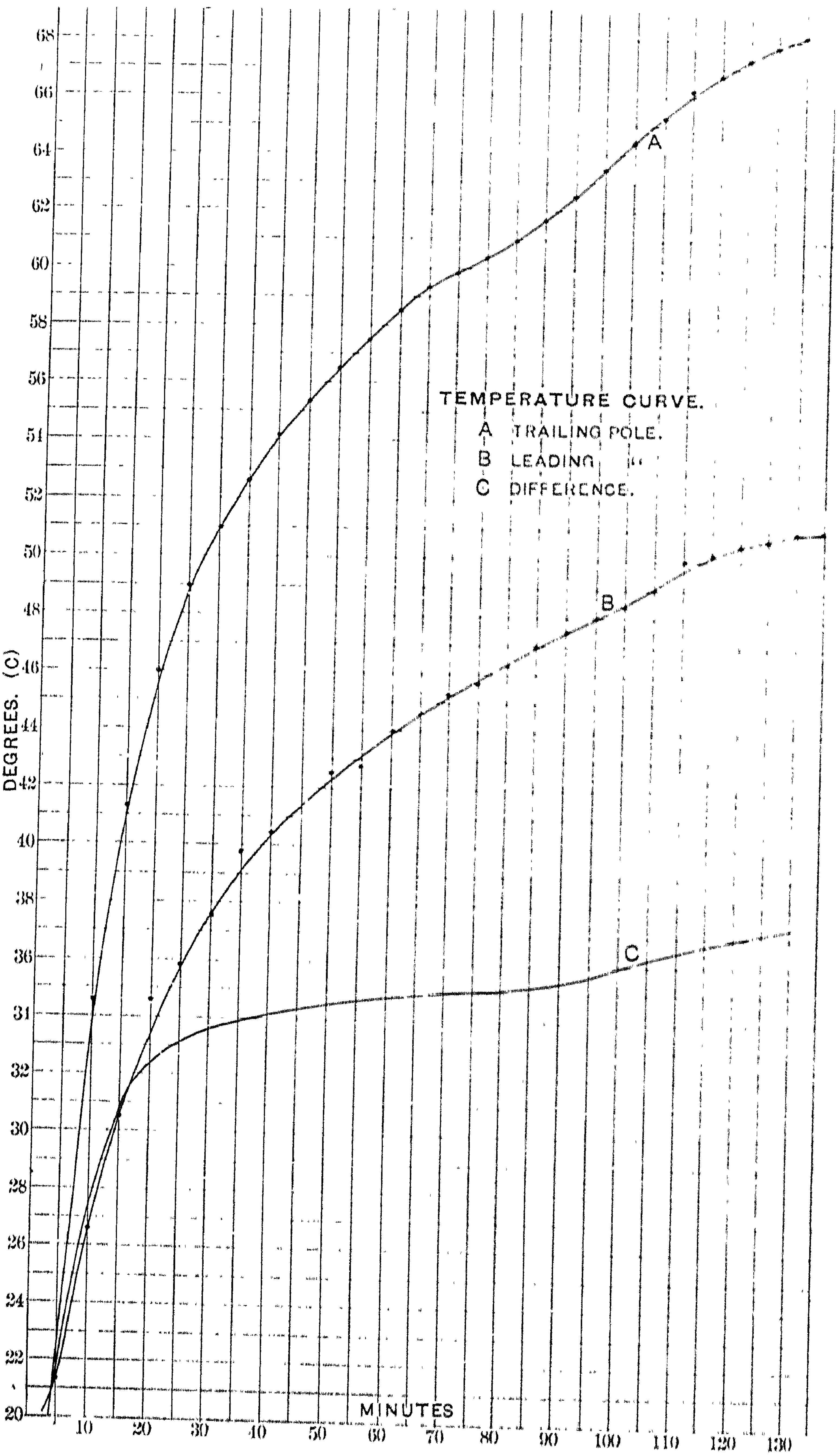
[1] C. P. Steinmetz, TRANSACTIONS, Vol. xii, p. 475.


TEMPERATURE CURVE.
A TRAILING POLE.
B LEADING "
C DIFFERENCE.
A
B
C
DEGREES. (C)
68
66
64
62
60
58
56
54
52
50
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MINUTES
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130

PLATE 8.

electromotive force curve A is indicative of the fifth harmonic; the side peaks have been sharpened, however, by the upper harmonics, and the central one somewhat broadened by the third.

The wave form of the electromotive force induced in the armature when the machine is loaded depends upon the character of the inductance curve of the armature coils. As already explained, the effect of the teeth upon the inductance curves is to introduce harmonics and cause irregularities in their contours. Practically the same number of harmonics are prominent in all the electromotive force curves, although the armature inductance has the effect of smoothing out the irregularities by giving the third harmonic greater prominence, and diminishing the effect of the higher harmonics. As the current rises and the magnetizing power of the armature becomes apparent, the harmonics introduced into the circuit by the variable inductance grow in amplitude. They combine with the harmonics of like order of the fundamental wave, and an electromotive force curve results that is compounded of a series of harmonics that depend upon the value of the armature current for their amplitude and phase positions.

A very small amount if any of the change in the form of the effective electromotive force waves is due to any departure of the original no-load wave of field flux from its initial wave form. In fact, to all practical intents and purposes the pulsations that occur in the magnetic reluctance of the field circuit are sensibly of the same intensity at full load as they are at no load. In other words the changes that occur in the permeance of the core of the armature as the load varies do not appreciably alter the permeance of the field circuit. The fundamental wave of magnetism and of electromotive force may therefore be regarded as always being present, if not always tangible.

Where alternating current generators are operated on circuits having a constant resistance for constant conditions of load, the disturbances that modify the form of the electromotive force and current waves can be attributed to the cyclic variations in the inductance of the system, and when these are known within a fair degree of approximation the character of the wave modifications that will result can be determined.

In the development of the experimental results contained in this paper the dynamo was loaded by inserting sets of incandescent lamps in the external circuit. A special point was made of keeping the external circuit entirely free of any inductance. The current curves are therefore necessarily proportional to the electromotive force curves. However, to make their relative value and form more easy of appreciation, they have been plotted and

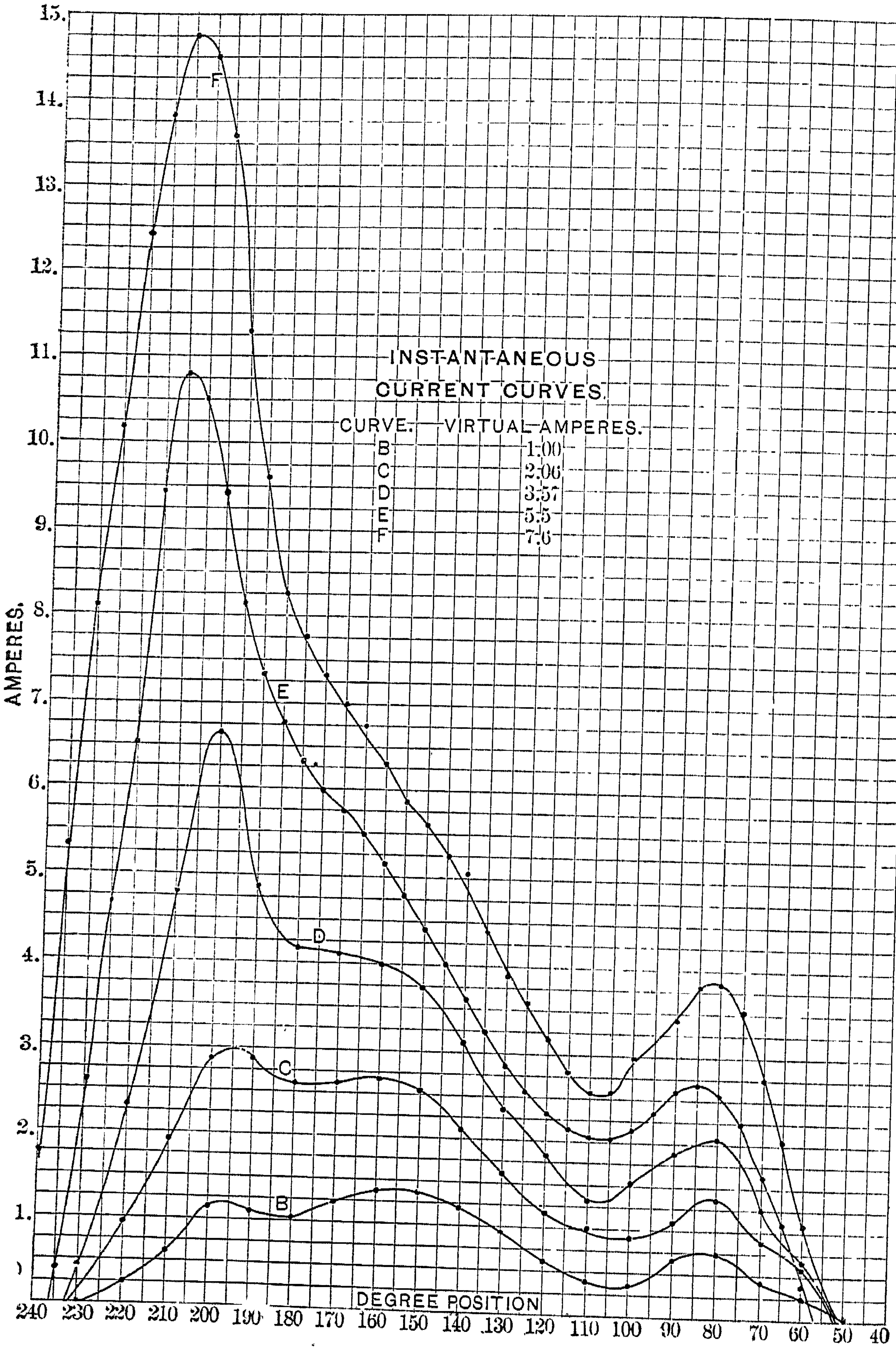

Plate 9.

are shown in Plate 9. The inductance curves of the coils that correspond to the alternating current curves are given in Plate 10. These curves were determined by selecting from the curves of

Plates 4 and 5, inductance values corresponding to the instantaneous values of the current curves and plotting them to the same degree positions.

It is noticeable, owing to the different scales used in plotting the curves, that the current curves seem more even and smoother than the electromotive force curves.

The inductance curves also are more nearly alike, both in phase and in amplitude, than the curves given in Plate 3. This is owing to the fact that the alternating currents all start from, and end at zero values when the coils are in positions of slight inductance, while they attain their maximum values at points of large inductance. For this reason the average inductance per cycle of the coils, is greater with an alternating current flowing in them than with a direct current of the same effective value. The alternating currents, for analogous reasons, force the induction curves up to the saturation limit marked by curve G of Plate 3, more rapidly than do the direct currents, and therefore for the same variation in effective current strength a less marked variation is caused in the inductance curves with these currents. The curves of Plate 3 certainly lead us to expect a greater variation, relatively to current intensity, in the armature inductance when the armature is in actual operation than that which is depicted in Plate 10.

It is a curious coincidence that the alternating current inductance curves all cross at a common point: namely, at the 164 ° position.

COUNTER ELECTROMOTIVE FORCE[1] CURVES.

Having the instantaneous current and inductance curves corresponding to a series of loads on the machine, it was a comparatively easy matter to determine the curves of the counter electromotive forces developed in the armature. To obtain a curve showing the cyclic variation of the induction set up in the coils by the armature current it is only necessary to plot the products of the ordinates of corresponding points on corresponding current and inductance curves. Such a set of curves obtained from a combination of the curves of Plates 9 and 10 are given in Plate 11.

If N represents the total flux that is induced in both coils by the armature current, divided by 10^8; L represents the inductance of the coils connected in series in henrys; S represents the total number of turns (572) of wire in both armature coils; and A represents 80 per cent. of the gross area of the armature core inside the coils, or 11 sq. cms.

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[1] In this paper the term "counter E. M. F." is used to indicate the E. M. F. which added to the effective E. M F. will equal the fundamental E. M. F. The counter E. M. F. is therefore equal and opposite to the inductance E. M. F., or the E. M F. of self-induction.

Then the induction per sq. cm. in the coils due to the armature current will equal,

$$B = \frac{N \times 10^8}{S\,A} = 15892 \times N. \qquad (2)$$

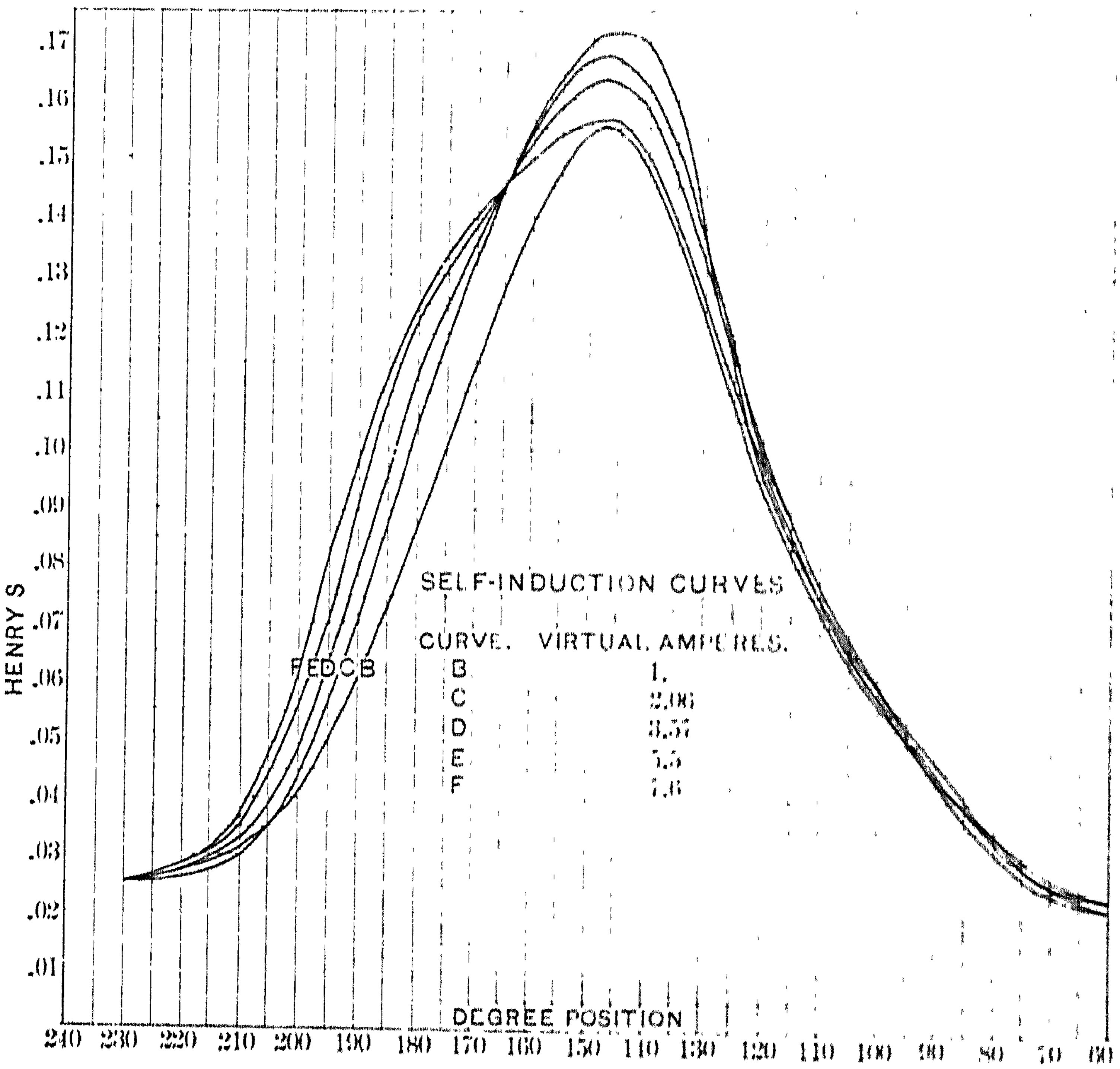

PLATE 10.

This equation gives the constant (15892) that must be applied to the scale of ordinates in Plates 11, 12 and 13 to determine the actual core densities induced by the armature currents.

Again, if i represents the instantaneous value of the armature current,

$$N = L\,i. \qquad (3)$$

and

$$d\,N = L \times d\,i + i \times d\,L, \qquad (4)$$

since L is a variable. Therefore, the counter electromotive force developed in the coils equals

$$e = -\left(-\frac{d\,N}{d\,t}\right) = \left(L\frac{d\,i}{d\,t} + i\frac{d\,L}{d\,t}\right). \tag{5}$$

In Plates 9, 10 and 11, we have the necessary curves for determining the instantaneous values of the counter electromotive force corresponding to any degree position by applying the principles underlying either of the above expressions. Both methods were used and were found to check within narrow limits. In Plates 12 and 13, the curves marked A have been taken from Plate 11. The ordinates of the curves marked B are equal to the

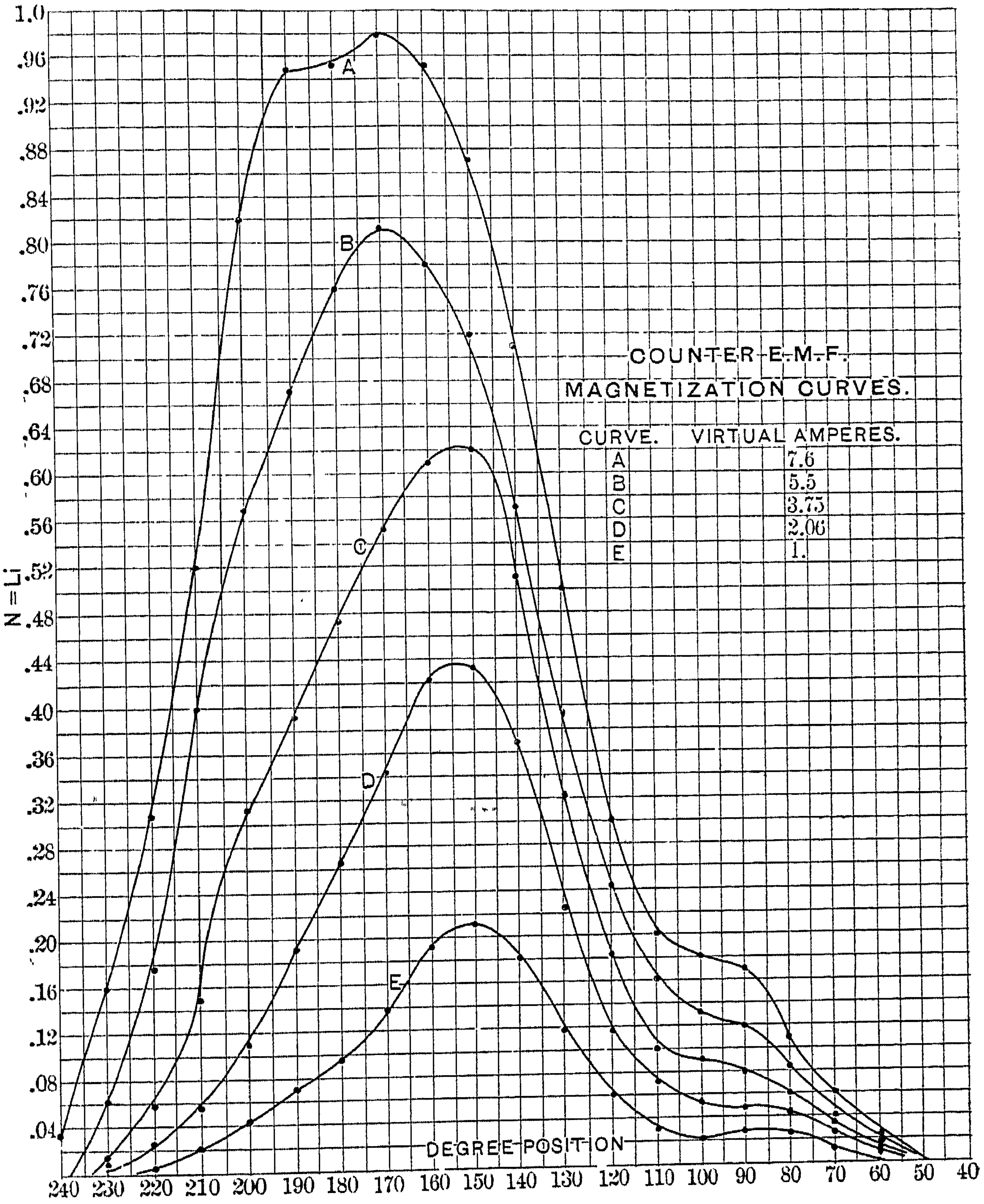

PLATE 11.

tangents of the angles made with the horizontal axis by lines drawn tangent to the A curves at the extremities of corresponding ordinates. The B curves are the calculated curves of counter electromotive force developed in the armature. The dotted curves were obtained by subtracting curves D and E of Plate 6

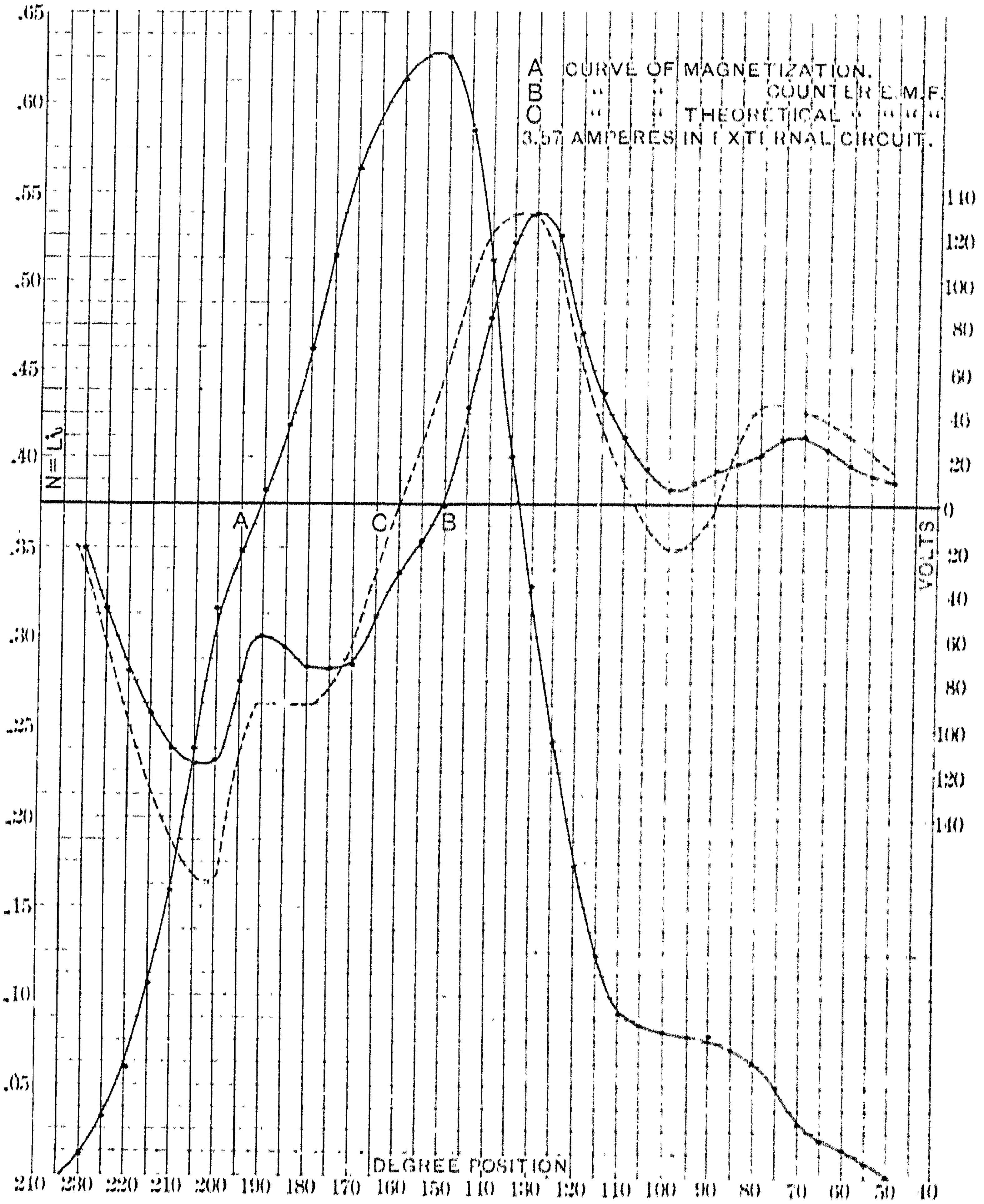

PLATE 12.

from curve A of Plate 6. On the assumption that the fundamental electromotive force wave of the machine does not change with the load, the dotted curve should also represent the counter electromotive force curve of the armature, and, in fact, the two curves should coincide. Plate 12 represents the poorest, and

Plate 13 one of the best results obtained from the application of this construction to each of the five sets of curves taken from the dynamo. When the fact is taken into account that the inductance of the coils was determined when the armature was at rest, the likeness between the dotted and the full curves is quite remarkable, and apparently justifies the assumptions that have been made. The counter electromotive force curves are highly

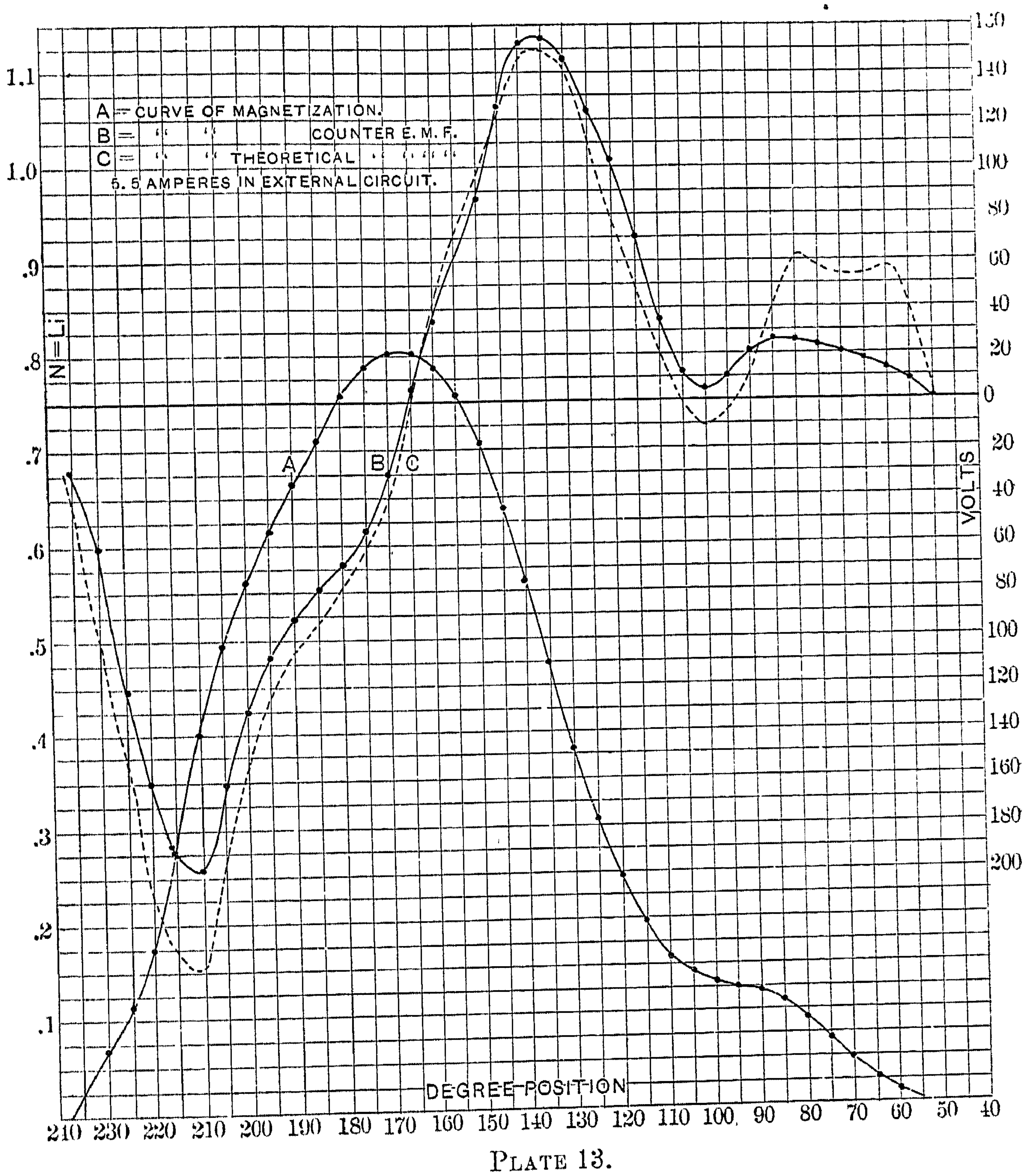

PLATE 13.

irregular in form. They oscillate from the positive to the negative value twice in a period instead of once, and are generally useful in filling up gaps. As shown, the curves represent the halves of one of the positive and of one of the negative loops; in other words, the half period of the curves lies between the 350° and 170° positions, and not between the 50° and 230° positions. This will be made more evident by a reference to curve *c* of Plate 18.

The whole series of inductance curves, as obtained by the subtraction method, are plotted in Plate 14. This assemblage shows that the curves follow one another in regular order in spite of their *lack of symmetry*, and it is interesting to note the receding of one and the building up of another "hump" in these curves, as illustrated at the lower left hand edge of the sheet.

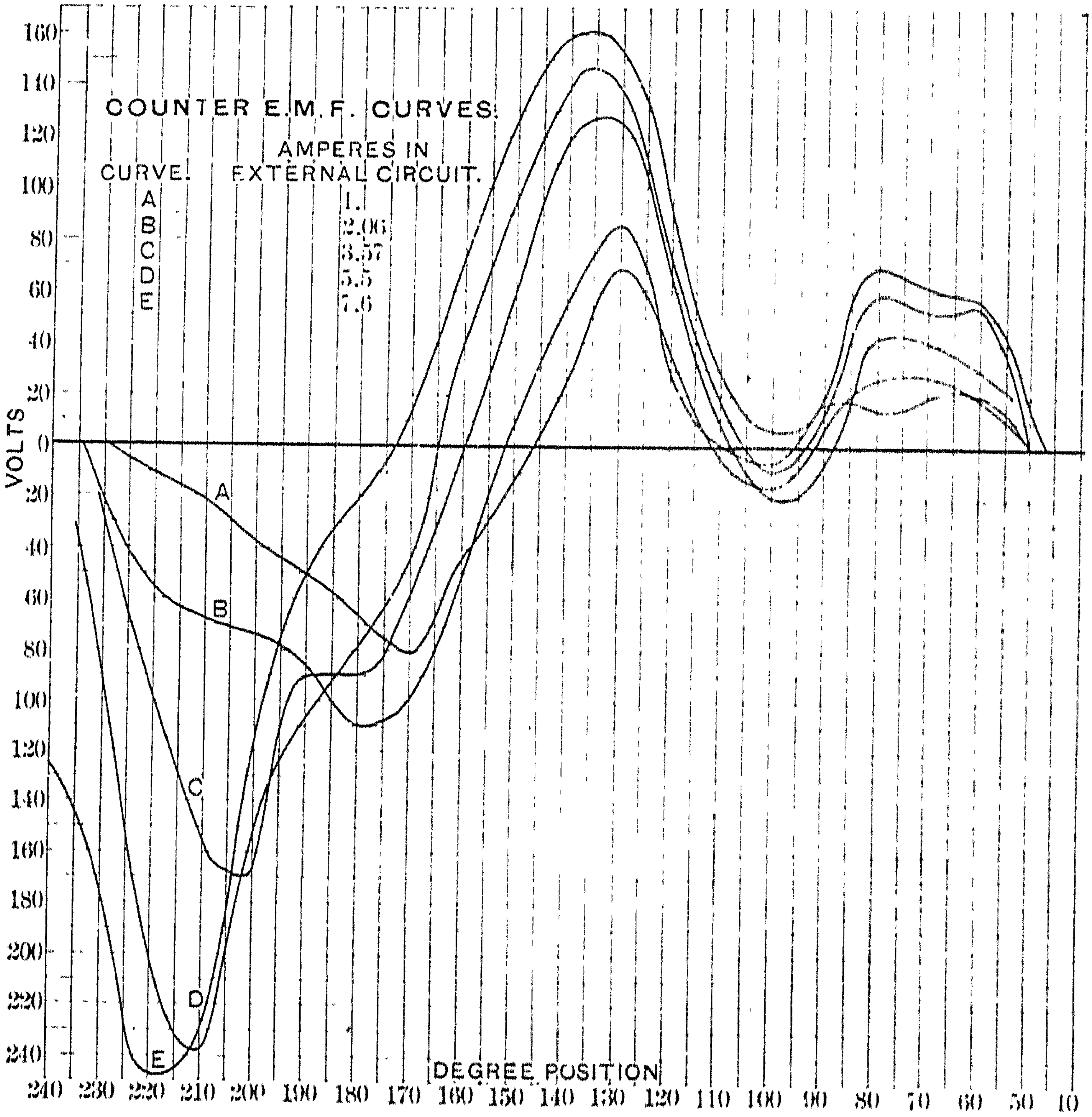

PLATE 14.

Plate 15 represents another phase of the subject. The curves traced in the fine black lines are the results of adding the calculated electromotive force curves determined by the means illustrated in Plates 12 and 13, to the corresponding effective or external electromotive force curves of Plate 6. They show the result of an attempt to work back from the effective electromotive force curves, or from the wave form of electromotive force appearing at the collector rings when the machine is loaded, to the fundamental electromotive force wave or the electromotive force wave appearing at the collector rings when the machine is running on open circuit.

The curve A, reproduced on this plate for comparison with the curves just mentioned, is the same as curve A of Plate 6. The agreement between the curves is marked. The derived curves show the greatest departure from the fundamental curve early in the cycle, between the 70° and the 110° positions. This is due to the fact that the initial "hump" at the 90° position of the induction curves was not developed with sufficient care. A very slight change in the contour of the induction curves at this point makes a great difference in the form of the counter electromotive force curves, owing to its effect in altering the direction of the tangents drawn to the magnetization curves of Plate 11. On the whole the likeness between the curves is well within the limits of the errors of observation.

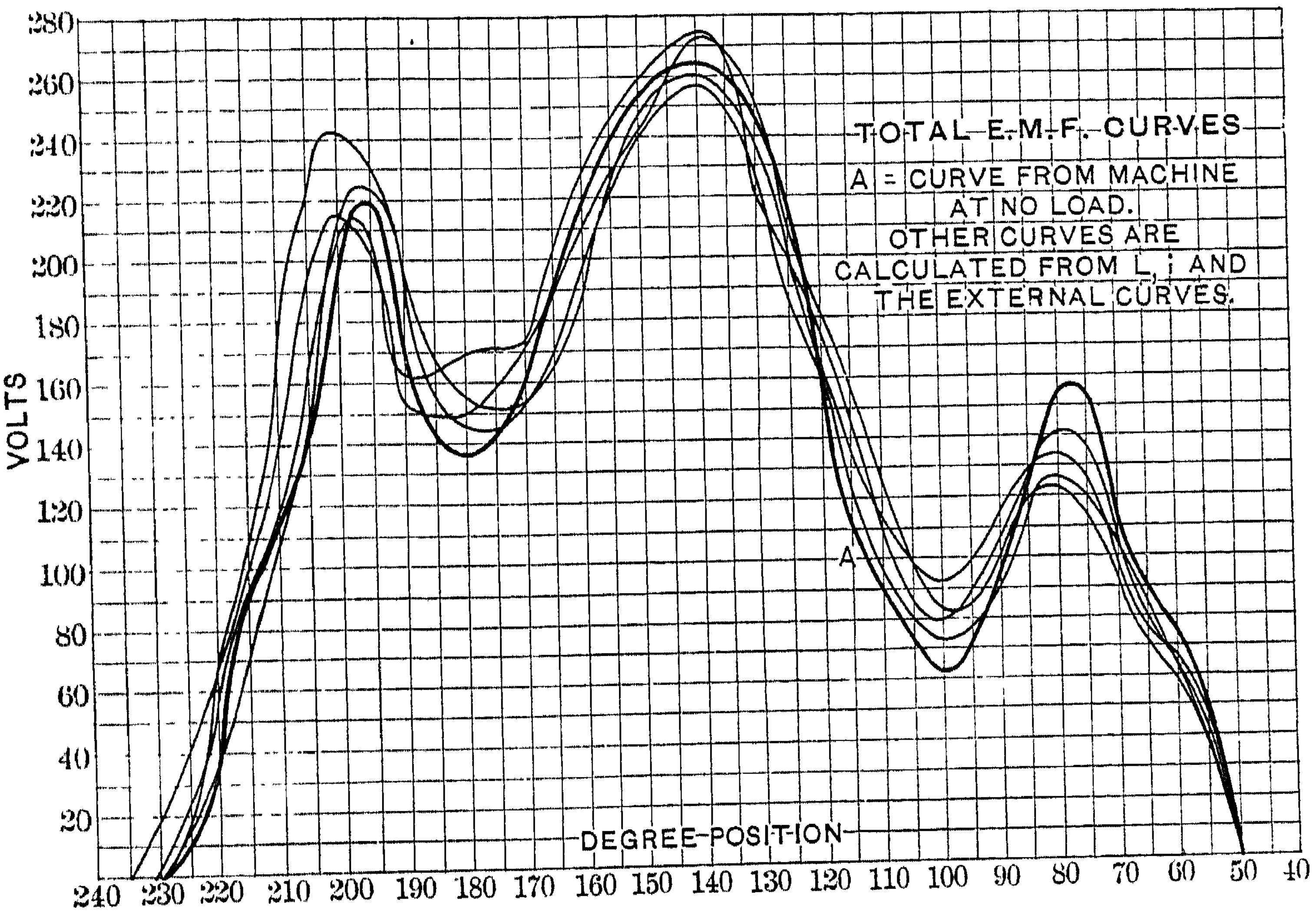

PLATE 15.

DERIVATION OF CURRENT CURVES.

Another interesting set of curves is shown in Plate 16. The success attained in working out the counter electromotive force curves, led to a series of calculations to determine to what extent the form of the current curves was influenced by the shifting of the phase of the inductance curves with the load. To this end an average of the inductance waves A, B, C, D and E of Plate 3 was taken to represent the average inductance wave of the armature for all loads. This curve is shown as curve B of plate 16. With this curve and the fundamental electromotive force wave A, forming a basis for calculation, the current that will flow with any given resistance in the circuit can be readily determined, provided that the curve B is taken to represent all of the variations that occur in the armature inductance.[1] The relation existing between the impressed electromotive force, the current and inductance in any alternating current circuit similar to the one under discussion is expressed by the equation

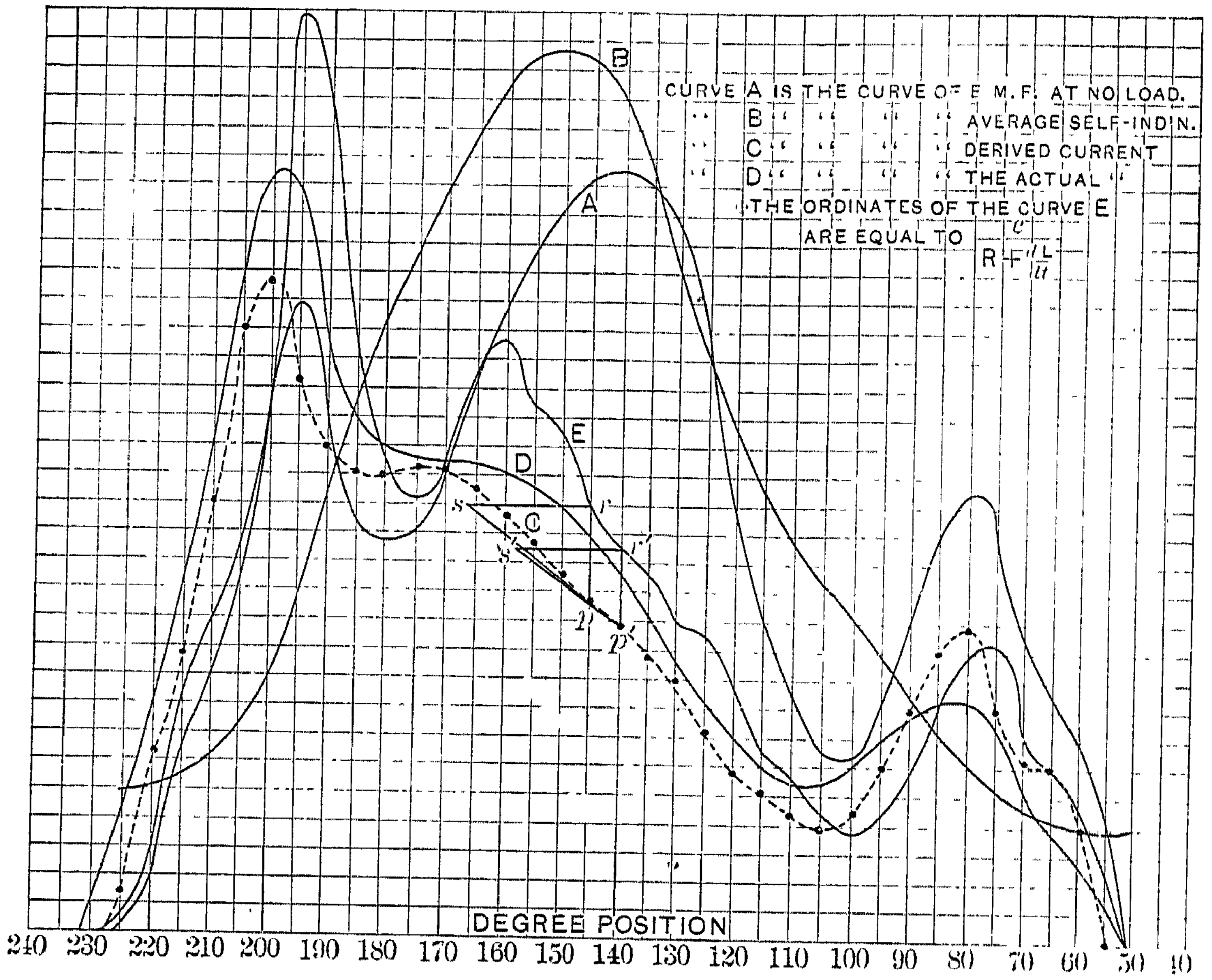

PLATE 16.

$$e = R\,i + \frac{d\,N}{d\,t}, \tag{6}$$

There e, i and $\left(\frac{2\,N \times 10^{8}}{S}\right)$ are, respectively, the instantaneous

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1. Steinmetz, "On the Law of Hysteresis." TRANSACTIONS, vol. xi., p 574. In this article the author calls attention to the solution of a problem that is analogous to this one, differing from it only to the extent that he works from an assumed sinusoidal inductance-electromotive force and a circuit of negligible resistance.

values of the impressed potential, current, and the magnetic flux induced by the current, and R is the resistance of the circuit.

Since $N = L\,i$, as above, (see equation 1), in the present case we have:

$$e = R\,i + L\frac{d\,i}{d\,t} + i\,\frac{d\,L}{d\,t}. \tag{7}$$

Then,

$$i\left(R + \frac{d\,L}{d\,t}\right) = e - L\,\frac{d\,i}{d\,t}, \tag{8}$$

and

$$i = \frac{e}{\left(R + \frac{d\,L}{d\,t}\right)} - \frac{L}{\left(R + \frac{d\,L}{d\,t}\right)} \times \frac{d\,i}{d\,t}. \tag{9}$$

By applying this formula to the curves of Plate 16, and following out a graphical construction, the successive instantaneous values of the current were finally determined, although in accomplishing this result the current curve E, which was the outcome of the process, had to be carried through successive cycles until it repeated itself.

The values of $\left(\frac{d\,L}{d\,t}\right)$ were taken from curve B. The ordinates of the curve A were then divided by the corresponding values of $R + \frac{d\,L}{d\,t}$, and these quotients, when plotted, gave the curve E.

Next, referring still to Plate 16, a point, as for instance p', was taken, that was thought to lie near the current curve, and the line $(p'\,r')$ drawn. From (r') the line

$$(r'\,s') = \frac{L}{R + \frac{d\,L}{d\,t}} \tag{10}$$

was laid off and $(s'\,p')$ drawn. Now from the assumed position of p',

$$\frac{p'\,r'}{r'\,s'} = \frac{p'\,r'}{\left[\frac{L}{R + \frac{d\,L}{d\,t}}\right]} = \frac{d\,i}{d\,t}, \tag{11}$$

and $(p'\,s')$ established the direction of the current curve, since from equation (9),

$$\left[\frac{L}{R + \frac{d\,L}{d\,t}}\right]\frac{d\,i}{d\,t} = \frac{e}{R + \frac{d\,L}{d\,t}} - i, \tag{12}$$

and

$$\frac{d\,i}{d\,t} = \frac{\dfrac{e}{R + \dfrac{d\,L}{d\,t}} - i}{\left[\dfrac{L}{R + \dfrac{d\,L}{d\,t}}\right]} \tag{13}$$

and therefore,

$(p'\,r')$ approximated the value of $\dfrac{e}{R + \dfrac{d\,L}{d\,t}} - i.$ (14)

By taking another point p on $p'\,s'$, and continuing the construction, a chain made up of short lengths $p'\,p$ was obtained which ultimately developed into the periodic wave c, for which the values of

$$p'\,r' = \frac{e}{R + \dfrac{d\,L}{d\,t}} - i. \tag{15}$$

The graphical construction used is not new. It is an adaptation of one of Dr. Sumpner's[1] unique methods of treating alternating current problems, and I have developed it here simply as a matter of interest in connection with the discussion.

Returning to the curves, it is noticeable that the dotted curve C resembles the current curves of Plate 9 very closely. Comparing it with curve D, which is a current curve taken from the machine, with 55 ohms resistance in the complete circuit, the chief difference noticed is that the right hand peak of the dotted curve is a little high, and the left hand peak a little low, and that the curve as a whole is somewhat depressed below the curve D. The differences between the curves are, however, not very marked. They result largely from the curve B having a less amplitude and smaller slope than the alternating current inductance curves of Plate 8, since it is derived from the direct current inductance curves of Plate 3.

The construction indicates a method that can be employed with success in determining before the machines are built, the wave forms that will be developed by alternators. It is possible to predetermine the fundamental electromotive force and inductance waves of an alternator, by the application of modern methods of design, and from these the load curves and armature reactions can be ascertained by processes analogous to those shown here.

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[1] Dr. W. E. Sumpner, *Philosophical Magazine*, June, 1887, p. 470.

If in the present case it had been desired to calculate the actual current curve with great exactness, an extension of the method used could have been employed. This elaboration necessitates taking the inductance values from Plates 4 and 5, as each point on the current curve is fixed. The process represents a refinement, however, that is hardly warranted in view of the good approximations resulting from the use of the less tedious plan.

OVER-COMPOUNDING.

It was noticed during the test that the armature reaction caused an increase in the total effective potential for certain ranges of load.

This phenomenon has been noted by other writers, and in his paper before the INSTITUTE, already referred to, Steinmetz has pointed out an explanation for it. Curve A of Plate 17 is the external characteristic of the dynamo, with constant field excitation, and coils 1 and 2 alone in action. The curve was plotted from the readings of a Weston voltmeter and a Siemens dynamometer connected in the external circuit. The load was a non-inductive one, and the speed of the dynamo averaged 1,450 r. p. m., which is equivalent to a frequency of a little over 24 periods per second.

The line R represents by its slope the resistance of the two coils, and curve B, which was obtained from the sum of the ordinates of the curves A and R, is the total effective E. M. F. characteristic of the coil. It will be noticed that the curve B shows an over-compounding effect up to a load of 7 amperes, and that the total effective E. M. F. was a maximum for a current of 4 amperes in the coils.

The term "armature reaction," as used above, is not intended to convey the idea that the current in the coils has any effect in varying or modifying the intensity of the flux passing through the field spools. The influence of the M. M. F. of the coils is purely a local one, and the paths traversed by the flux which it induces are confined to the air-gaps, poles and armature core. The influence of the armature inductance upon the flux density in the cores of the field spools is negligible, as a careful exploration established the fact that the field current was perfectly constant.

The compounding action of the armature currents in augmenting the effective voltage is a matter with which you are doubtless familiar. As a matter of interest, however, and in order to present a better picture of the wave forms involved, a series of curves has been plotted, that includes the power curves, and enables us to more readily appreciate the cycle of events that combine to produce this result. In Plate 18, curve A is the fundamental E. M. F. wave; curve B is the total effective E. M. F. wave and also represents the instantaneous values of the current; and curve C is the counter E. M. F. wave. Curve D is the power curve of the machine determined by taking the product of the corresponding in-

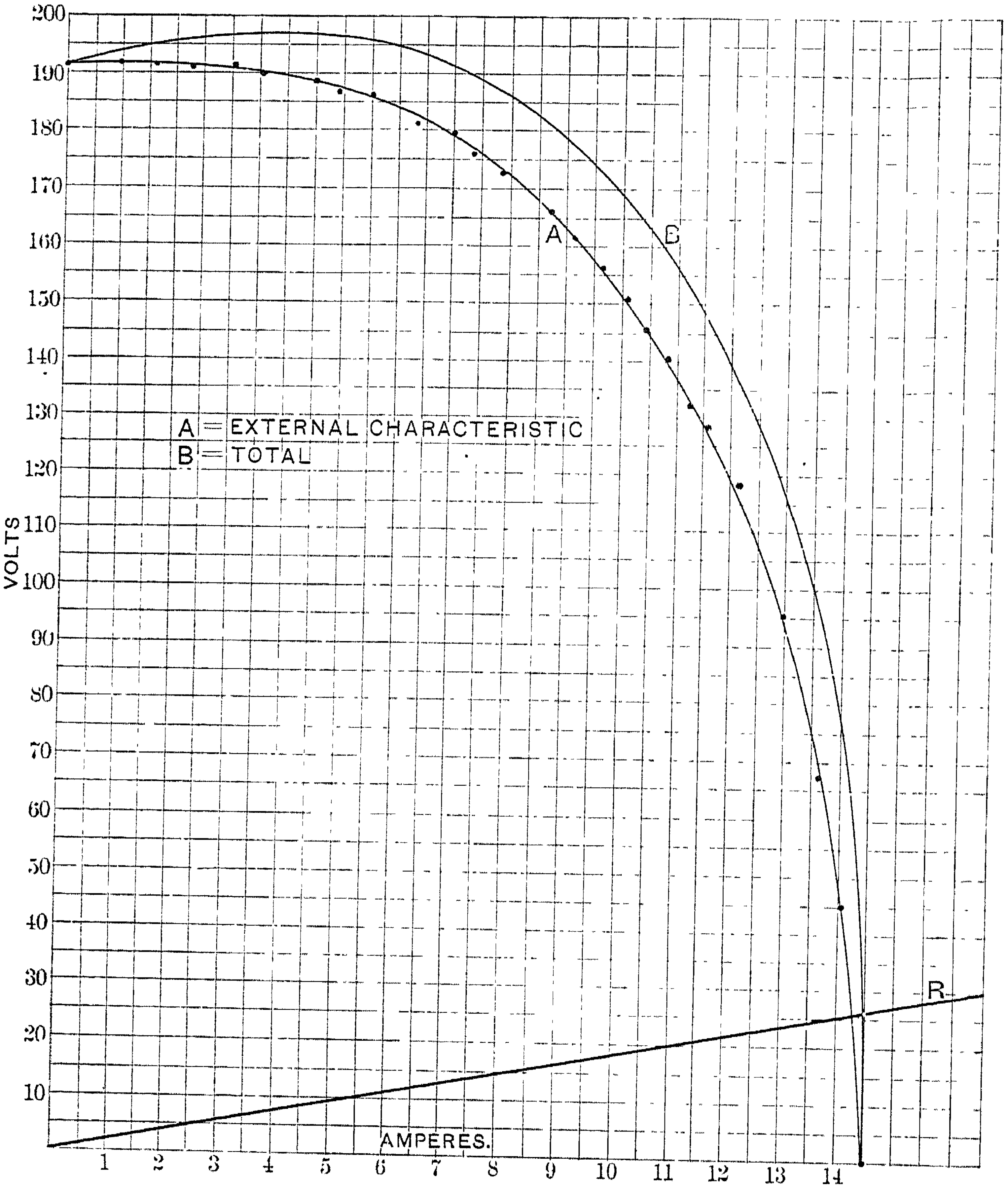

PLATE 17.

stantaneous values of the current and the fundamental E. M. F. curve. Curve E is a power curve obtained by taking the product of the corresponding values of the current and the counter E. M. F. The power curve of the total power developed by the machine, and which is proportional to the product of the corresponding values of the current and effective E. M. F. curves, is not plotted, as its ordinates are proportional to the square of those of curve B, and equal to the vertical distances intercepted between the power curves D and E.

It will be noticed that the power area inclosed between the curve E and the base line changes sign four times in a complete period, owing to the irregular form of the curve C, and that the sum of its positive and negative areas is not zero, but equal to a negative quantity.

Positive work done by the counter E. M. F. indicates power absorbed from the circuit. The energy consumed in overcoming the hysteresis and eddy current losses in transformer cores is a familiar example of this fact. Negative work performed by the counter E. M. F. in the same way represents power given to the circuit. In the present instance the negative area is due to a peculiar combination of irregular wave forms, involving the inductance curve, the current curve, the curve of the magnetism inducing the counter E. M. F., and the curve of counter E. M. F. The peaks of all the curves are shifted more and more in the direction of rotation as the load comes on, but some are given a greater displacement than others. The peak of the current curve, for instance, lags behind the peak of the inductance curve. In other words, the current is a maximum when the inductance is least. This results in the production of a wave of M. M. F. of self-induction that is in advance of the current, and that produces a wave of magnetism in the coils which reaches a maximum midway between the peaks of the inductance and current curves. These phase relationships can be followed out by comparing Plates 10, 9 and 11. The wave of inductance magnetism (curve A, Plate 11) induces a curve of inductance E. M. F. that has an effective phase displacement behind the current wave of less than 90°. This makes the effective phase displacement of the counter E. M. F. curve (curve C, Plate 12, and curve C, Plate 18) more than 90° in advance of the current curve, and therefore the product of the instantaneous values of the counter E. M. F. and current curves gives a power curve having an excess negative area. It is rather difficult to estimate the phase position of a wave that has an outline as irregular as that of the curve C of Plate 18, but it is best approximated by noting the location of its greatest positive area, and this, in the case in hand, is early in each half period.

CONCLUSIONS.

An inspection of curves B and D of Plate 18 shows that any decrease in the maximum slant of the curves of Plate 11 will decrease the amplitude of the 200° peaks of the counter E. M. F. curves, and thereby decrease their form factors, and at the same time decrease the form factors of the effective E. M. F. curves. This is what occurs in the case of curve D of Plate 11, owing to the great amplitude of the inductance loop for a value of the current of two amperes, which also accounts for the drop in the "form factor curve" of Fig. 6. This curve represents the form factors of the E. M. F. curves of Plate 6, and of the current curves of Plate 9, plotted relatively to the virtual value of the current flowing in the coils at the time the curves were taken. The form factors have been calculated according to Fleming's[1] definition, which is that the form factor equals the ratio of the square root of the mean square of the ordinates of the wave to the true mean ordinate of the wave.

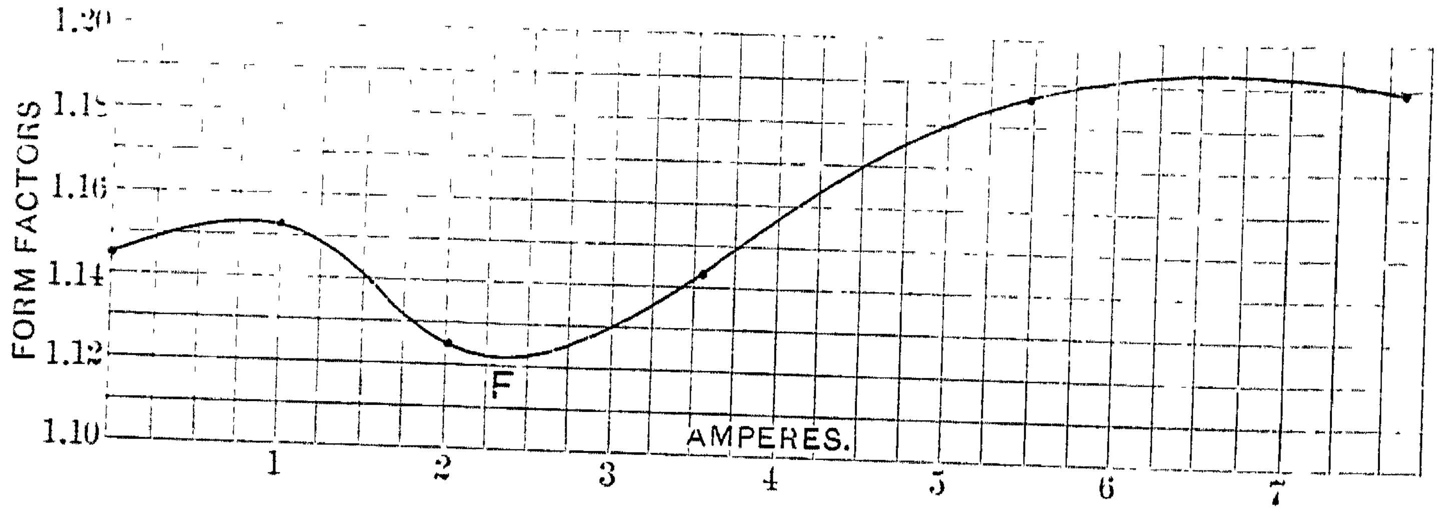

FIG. 6.

The influence of the inductance of the coils upon the form factor can best be appreciated by looking at the curves of Plate 10. They all have the same width of base, but vary in amplitude, and necessarily other things being equal, produce counter E. M. F. curves having the smallest form factors when currents which are favorable to a large armature inductance are flowing in the coils.

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[1] J. A. Fleming, "The Form Factor of Alternate Current Curves." London *Electrician*, vol. xxxvi., p. 338.

It is noticeable that the right sides of the curves of Plate 10 all have the same slant. They therefore produce counter E. M. F. loops, having similar shapes (see Plate 14). On the other hand, the left sides of these curves vary in shape, owing to variations in the reluctance at this part of the cycle. Greater variations, therefore, occur in the instantaneous values of the counter E. M. F. induced in this part of the cycle than in the former part, with the result of increasing the form factor where the induction curves corresponding to the current curves are relatively low and broad, and of decreasing the form factor of the counter E. M. F. curves where the inductance curves are narrow and high.

Again, since the maximum peak of the effective E. M. F. curve is opposite in sign and position to the leading peak of the corresponding counter E. M. F. curve, and since the sum of these peaks must not be greater than the adjacent peak of the fundamental E. M. F. wave, we see that an increase in the form factor of a counter E. M. F. curve causes an increase in the form factor of the corresponding effective E. M. F. curve, and vice versa. That the changes in the form factor of the effective E. M. F. curves are approximately directly proportional to the mean width of the inductance loops, and inversely proportional to the amplitude of the inductance loops. These conclusions are amply sustained by the data presented.

The variations that take place in the value of the armature inductance when the load is increased, lead us to expect that there is a proportionally greater increase in the value of the counter E. M. F. as the current passes 2 amperes in value. An accelerated increase in the counter E. M. F. would have the effect of making the compounding proportionally greater, for it would add a proportionately greater amount of energy to the circuit, owing to the fact that although the amplitude of the counter E. M. F. is increased, its phase position remains practically the same. That a positive acceleration does occur in the rate of increase of the counter E. M. F. is true, and also, that this is followed by a negative acceleration. The value of the counter E. M. F. depends upon the intensity of the current, and increases as the current increases. It, however, does not increase at a rate that is proportional to the rate of increase of the average intensity of the current, for its value also depends upon the armature inductance which first increases to a maximum and then decreases, as is shown by the curves of Plate 10. We, therefore, find that as the average intensity of the armature current is uniformly increased, the counter E. M. F. experiences a proportionally greater rate of increase up to a certain point and that after this point is passed, its rate of increase is diminished.

This means that as the load comes on, the value of the effective electromotive force increases above the value of the fundamental wave for a time. For from the relative positions of the highest peaks of the curves B and C of Plate 11, it will be evident that any increase in the virtual value of the counter E. M. F. will cause the virtual value of the effective E. M. F. to increase also, and any increase in the virtual value of the effective E. M. F. above the virtual value of the fundamental wave of E. M. F. raises the potential at the brushes. The fact that the virtual value of the effective E. M. F. finally falls below that of the open circuit E. M. F is due to the ultimate gradual decline in the armature inductance wave and a consequent change in the form of the counter E. M. F. magnetization curve, which reduce the amplitude of the leading peaks and augment the amplitudes of the trailing peaks of the counter E. M. F. curves. This effect is apparent in curves D and E of Plate 14.

As exemplified in the curves of Plate 7, we find that the maximum induction threading the armature coils occurs when the form factor is least, and the armature inductance greatest. Again, the analysis of the forces involved shows us that the point F on the form factor curve of Fig. 6, and the point T on the "B & H curve" of Fig. 5, are intimately connected.

The double rôle played by the permeability of the iron of the armature core and pole-pieces, and the importance that may be attached to the permeability of the iron under favorable conditions is forcibly brought to our minds. We are enabled to see a little more clearly the complex relations of the interlinked forces that act and react upon one another in the conflict of the air-gaps, and there is established a basis for the analysis of a problem that has been more or less obscure.

Purdue University, Lafayette, Ind.,
June, 1897.

DISCUSSION.

THE CHAIRMAN [Vice President Steinmetz]:—This paper has been very interesting to me in-so-far as it gives one of the various effects taking place in the armature of an alternator separate from the others. Here we have an alternator having a very strong self-induction in the armature, with practically no armature reaction, that is no magnetizing effect of the armature on the magnetic field. You see here separate from all the other effects that of the self-induction and of the variation of self-induction. A very interesting feature is that the self-induction under these circumstances is not a wattless electromotive force, but that there exists an energy component of self-induction. Thus this paper brings experimental facts for a feature to which I drew attention some time ago, that under such circumstances an alternator without field excitation can yield electric power by the energy component of self-induction or can run as a synchronous motor, the energy component of self-induction yielding mechanical power. I may remark that besides this self-induction discussed here, the main phenomenon taking place under load in an alternator is armature reaction; that is the magnetic action of the armature currents on the magnetic circuit, and under circumstances a fluctuation of the magnetic reluctance of the field. In modern alternators usually armature reaction preponderates over the self-induction of the armature to such an extent that very frequently the armature reaction is three or four times larger than the effect due to the armature self-induction. Mostly, however, the self-induction is a very important factor also, and is dealt with very completely here.

MR. GANO S. DUNN:—It is not quite appropriate to the paper, but I have been interested in making measurements of the self-induction of direct current armatures, and if Prof. Goldsborough has made any observations on the self-induction of a coil in the neutral space and under a pole-piece, it would be very interesting if he would state what he finds the relative self-inductions to be.

PROF. GOLDSBOROUGH:—I have not made any determinations of the character of the variation of the inductance of separate coils of direct current machines, but I think you will find that the variation of self-induction as shown in this paper dealing with the Brush machine, is practically the same. Since the teeth on this machine are very large, they produce an effect simply magnified over and above what it would be in the ordinary direct current machine. If you move two teeth of an armature from under the pole tips into the neutral space, you will find there will be a variation in the coefficient of self-induction of the coil between them, that is practically the same as that shown in this paper. The curve of self-induction would be a little flatter at the top in such a machine, than in the machine I experimented on. In all probability, supposing this to be one pole of our machine and this another (illustrating), the curve of variable self-induction of a coil would be a very flat-topped curve for points immediately under the pole-faces and would become small again as the coil passed between the poles.

MR. DUNN:—As I followed the paper this morning, the coefficients of self-induction were measured separately and without the influence of the mutual induction of the other coil.

PROF. GOLDSBOROUGH:—That is true.

MR. DUNN:—Does this coefficient that you speak of include the mutual induction of the other rings of the armature?

PROF. GOLDSBOROUGH:—No.

MR. DUNN:—My experience is that that very greatly modifies self-induction.

PROF. GOLDSBOROUGH:—It does.

MR. DUNN:—Therefore the results which were obtained with a single coil could not be expected to suffice for a coil under the actual conditions of direct current commutation.

PROF. GOLDSBOROUGH:—That is true. The machine which my paper discusses, gives the characteristic variation between the current and the electromotive force appearing at the brushes shown in Plate 17, where only one pair of the armature coils is active. On the other hand, this same machine operated with all the armature coils connected in series, develops about 500 instead of 190 volts, and develops a characteristic which bends over a little bit more and then goes straight down, so that you have perfect regulation for constant current between about 300 volts and zero volts. With all the coils connected in series and to collector rings, this machine can be short-circuited while carrying its maximum load, and the needle of the electro-dynamometer registering the current (which will not exceed 10 amperes) will not vary at all. The self-induction of the armature is increased approximately as the square of the number of the conductors as you take in the mutual induction of the adjacent coils. Just as you said, the mutual induction modifies the action of the machine considerably.

THE CHAIRMAN:—I do not think there is any great difference in the self-induction of a single coil and the self-induction of the coil as a part of the whole armature, including the mutual induction with neighboring coils, provided the conditions are such as would be the case in a continuous current machine under commutation. It would be different indeed if the current reversed simultaneously in a number of coils in series.

There is, however, a very essential difference in the self-induction of the commutation of a continuous current machine and that given here. If you take a continuous current armature and measure the self-induction of a coil by the method of reversals or by any other means, say by sending alternating currents through it, you find the value of self-induction larger than it is under commutation as a direct current machine, due to the very great difference of frequency. The frequency of commutation of direct current machines usually averages 400 to 800 cycles. For these frequencies the field structure which is in the magnetic circuit of the commutated coil, is practically short-circuited. There is practically no commutating flux passing through the field, but all the flux passes through the air gap across the top of the slot. Therefore the real self-induction of commutation is less than the self-induction measured at low frequencies where the magnetic flux changes in the whole magnetic structure of the machine.

MR. DUNN:—The extremely high frequency in the direct current machine undoubtedly affects the coefficients of self-induction, although I have never measured it to bring out the point that you just made; but I do not see how the mutual induction can be so small a factor. I look upon the conditions as these: An iron core with two windings, one of which is the main part of the armature winding, connected with the constant potential circuit, and the other a short-circuited coil under the act of commutation. When the current reverses in the single coil the effect of mutual induction will be to send current through the rest of the winding out into the mains. Did I understand you to say that the mutual induction had a very small effect?

THE CHAIRMAN:—In an ordinary direct current armature, with closed circuit drum or ring winding, if two coils commutate simultaneously or even in succession, and these coils lie in the same slot, thus having the same magnetic circuit of self-induction, then there is a more marked mutual inductive effect, which may be either helpful for commutation, or more commonly objectionable. If, however, not more than one coil at a time commutates in the same slot, I do not think there can be much mutual induction.

MR. DUNN:—Let us suppose that on the armature there are thirty coils and one is undergoing commutation. The resistance of the others would be twenty-nine times the resistance of the coil under commutation, but if the coefficient of mutual induction were high enough, a current as large as twenty per cent. even of the current in the commutated coil might flow.

THE CHAIRMAN:—Yes; but these coils are not individual coils closed upon themselves, but are in series, and are spreading over the whole surface of the armature in such a way that in a part of the series turns the E. M. F. of mutual induction is equal but opposite to that in the other part, so that the resultant effect is zero.

MR. DUNN:—I look upon them as being in series with each other, not over the whole of the armature, but over the two halves of the armature in multiple, and in series with the generating dynamo. The path of the current generated by mutual induction would be up one-half of the armature into the main, through the generating dynamo into the left half of the armature, and not in a complete circle around the armature.

THE CHAIRMAN:—I do not think you will find much, because in a symmetrical magnetic structure the resultant effect of mutual induction must necessarily be zero, and thus only due to a lack of symmetry, mutual inductive E. M. F's could be produced in the armature outside of the commutated coil, but since you have the whole resistance of the generator in circuit, I cannot see that you can get a noticeable effect; I never noticed any.

MR. DUNN:—I understood you to say that you had measured it. My question was as to what the values were. I have not measured it but I have always thought it was large.

THE CHAIRMAN:—I have never measured it accurately. The only measurements I made were approximate. I measured the self-induction of the continuous current machine under commutation with ordinary alternating current frequencies, and then with frequencies varying from 500 to 1000 cycles per second and found very much lower values in the latter case, which brings me to the opinion that the lack of responsivity of the magnetic circuit reduces self-induction.

The following paper on "Electric Metering from the Station Standpoint" was then read by Mr. Caryl D. Haskins:

A paper presented at the 14th General Meeting of the American Institute of Electrical Engineers, Eliot, Me., July 27th, 1897. Vice-President Steinmetz in the Chair.

ELECTRIC METERING FROM THE STATION STANDPOINT.

BY CARYL D. HASKINS.

It has occurred to me that in presenting a paper to the INSTITUTE upon such a subject as that which I have selected, I may appear to have departed too entirely from the technical side of our profession, and to have selected a line of argument which would have been more appropriate before a more commercial body. But in my opinion such is not the case, for I find that almost every merit, in, or objection to metering apparatus, or in connection with the use of it, is dependent upon some point involving engineering skill.

The general adoption of the electric meter is in itself an endorsement of the precise methods which characterize engineering practice. It is, indeed, a well established fact to-day, well borne out by data from widely separated portions of the country, that the average electric lighting station can do one-third more business with the same station capacity on a meter basis, than it could upon a contract basis, under what were nominally equivalent contract rates, netting at the same time the same revenue per light as formerly. In other words, it is apparently well established that $33\frac{1}{3}$ per cent. represents the average wastefulness of average human nature in connection with the use of light.

In many central stations to-day, I find that, whilst managers are almost universal in favor of an exclusively meter basis, a large proportion are still in ignorance as to what qualities they should seek and what they should avoid in selecting a meter.

In response to an inquiry as to what merits in a meter are necessary to success, a common reply is, accuracy, durability, registration in a simple unit easily comprehended by the customer, and ability to withstand tampering. These points are probably of importance in about the sequence in which they are commonly stated; but they are too sweeping, too entirely generic and too slightly specific to be in any high degree helpful.

Let us, for example, consider the broad question of accuracy. A meter, which will be accurate under commercial conditions from quarter load to full load within $\frac{1}{10}$ of 1 per cent., or a meter which will *start* on 1 per cent. of its rated capacity, are neither of them necessarily either the most accurate or the best for general commercial use. This latter point is one which is frequently raised. The fact that a meter will start on 1 per cent. of its rated capacity is in reality no sure criterion of the accuracy of that meter, even on light loads. It is not necessarily even good evidence; yet I find that in very many cases this is almost the only test applied to meters at the time of purchase. The percentage of accuracy at light loads is very important, more important, I believe, than is commonly appreciated; but I am perfectly safe in saying, that a meter which will run within 5 per cent. of zero error on 5 per cent. of its rated capacity may readily be a much better meter, even though it will not run at all on 1 per cent. of its rated capacity, than one which will run on 1 per cent. of its rated capacity but in regard to which no evidence is at hand as to its percentage of accuracy at reasonably low loads.

Ability to start on very light loads is certainly an *indication* of merit and is important, but it is not nearly as important a point to determine as is the lowest load at which a meter begins to register with fair accuracy. I have inspected a very large number of meters which would start on phenomenally low loads and which would yet fail to give anything like approximate accuracy at reasonably low loads.

In considering the question of accuracy, therefore, the first two steps should be to determine the accuracy of the meter by actual measurements at full and medium load; and also at a reasonably low load; say, for example, 5 per cent. of the meter's rating.

That low load accuracy is really of vital importance is well shown by the fact, that with the average 24-hour station, in the neighborhood of 15 per cent. of the total station output goes to feed one and two lamp loads. Yet in the face of this I have seen large installations of meters reported as entirely satisfactory, tested with frequency and care under admirable systems, but only at full or medium loads, and yet failing to account for more than 50 per cent. of the one and two lamp loads, or in other words, losing to the illuminating company an average of probably 7½ per cent of the revenue which their measured station output should give them, after deducting for legitimate losses.

Granting that, having determined the actual percentage of accuracy obtainable at light, medium and full loads, a very important and in fact probably the most important evidence as to accuracy has been obtained, there still remains much information of vital importance which should be sought and which should materially influence a decision.

One point which is very commonly neglected, but which is, nevertheless, quite essential, is the ability of a meter to give accurate results for brief periods on overloads. This is a point at which many meters fail, and it is also a point which, odd as it may seem, is intimately related to light load accuracy. It may be laid down as a rule, that in station operation the smallest meter which will do the work should always be used. Otherwise, however good the meter on light loads, much of the light load revenue must be lost in the effort to take care of occasional heavy loads. Extremely heavy loads are generally of brief duration, and on these loads a meter should operate with accuracy and also without injury to itself. This, therefore, should be an early point of investigation in selecting a meter.

On alternating circuits, inductive loads are becoming commoner every day. The wider use of fan motors and other alternating power devices, the rapidly growing popularity of alternating circuit arc lamps, and the commoner use of inductive dimmers, all render it essential that a meter should be accurate irrespective of the power factor. The company which insists upon charging its patrons for power delivered to fan motors on a basis of volt-amperes, is obviously rendering itself unpopular, greatly limiting its business and giving its competitor, or competitors, the best of opportunity for intruding; yet many such companies exist to-day, and they exist not because they are following a wise policy in their own estimation, but because they are ignorant of what they should look for in the meter which they are using.

Again, there are few electric light stations to-day of any considerable size and age which are not operating some smooth core and some tooth core alternating armatures. It is, therefore, important that the meters in service at such stations should be equally accurate on any shape of wave; yet many meters fail in this particular; and seldom, if ever, is the point made a subject for investigation in selecting measuring apparatus.

This same consideration holds good in connection with frequency, and this is a point which it is difficult to overcome in most metering devices; but it is one which should be earnestly sought and which is of importance both to the station and to the consumer.

Even after this long list of points which must be investigated, as contributing to the broad question of accuracy, there are others which also merit consideration, but to a less degree. Such, for example, as barometric conditions (more especially altitude), temperature and humidity. These all have direct bearing upon the question and all enter into the every day conditions of central station practice.

Summing up the question of accuracy, we may say, therefore, that the following points should be investigated with care.

Ordinary volt-ampere accuracy;
Accuracy on inductive loads;
Accuracy on varying wave forms;
Accuracy on overload;
Accuracy on varying frequencies;
Influence on accuracy of variations of temperature, barometric conditions and humidity.

The second point, which is commonly given consideration in the selection of a meter, is that of life. This is a question which must depend more upon good judgment than upon any test which can be applied; for it is in reality no test of the enduring qualities of a meter to run it at excessively high speed for a relatively brief time. The life of a meter, in other words, cannot be measured by revolutions, irrespective of the speed of those revolutions; nor can it be determined by the speed at which it rotates alone.

Ninety per cent. of all the wear in a meter, centres in the case of motor meters at the single jewel bearing, which is almost universal. The two chief factors which have influence upon the mere mechanical life are the weight of the moving mechanism, and its speed, the variation of the area of the point of contact being, of course, always so small as to be out of the consideration.

A low speed meter is usually the best meter, provided the speed be not carried so very low as to threaten the accuracy of the meter on light loads, by reason of being held up by intermittent friction in the form of dust or a spider. Practice has indicated that low speed is more conducive to long life than is light weight of the moving mechanism, although both are, of course, very important. More important than either, however, is the quality of the material used at the points of friction and the ease with which the friction parts can be renewed. The best of sapphire is barely good enough, and the pivot end must be of correct shape, burnished to the highest degree, and its point must be absolutely concentric with the centre of movement.

More than half of the meter jewels which are destroyed are rendered useless, not by the rotary motion of the shaft, but by reciprocating motion of the shaft, due to vibration. Hence it is very necessary that the jewels should be in some way cushioned, for vibration cannot be always avoided.

These are all, I admit, mechanical considerations, but they compass much of failure or success in electric metering. The purely electrical features of the meter contribute no grave factor of consideration in connection with the life question, always supposing that the copper is ample and the potential windings are so distributed and so ventilated as to preclude a burnout.

Passing over the central station man's third factor for consideration, that of the best unit of measurement, as one which is practically a closed question, we are brought face to face with his lamentable fourth point, the necessity that the meter should be able to withstand tampering. It is a regrettable fact, that this is a consideration which is coming daily into more prominence; but light has to be sold to all sorts and conditions of people; and apparently the transgressor against meters is even more common than the transgressor against taxes; and this is a growing evil, largely, perhaps, because of the lax conditions of the laws, which can be invoked to protect the meter owner in many of our states.

The methods which are commonly practiced in tampering with meters can scarcely form any proper part of a technical paper; but as this paper may go into the hands of some who need the knowledge to guard themselves and their interests, it can do no harm to briefly state the common methods used, not only that they may be guarded against, but also that meters may be selected which lend themselves least readily to such practices. It is not unusual to place large masses of iron above, below or at the side of meters, but this practice is falling somewhat into disrepute among its advocates, since even they have in time discovered that there is a class of meter which it accelerates.

Electromagnets, drawing their energy from the circuits under measurement and used as the iron was formerly used, are now not uncommon, and it is difficult to prove in court deliberate evil intent.

Meter covers and bases are drilled, and wires, broom straws and the like inserted. Covers are pried up and healthy colonies of spiders introduced.

Ingenious individuals have even been reported as finding profit in a clever apparatus for injecting fine iron filings into meters by means of a bellows.

All of these things need to be watched for and guarded against.

The question of installation and care of meters, is a wide subject, and in connection with it I shall endeavor to mention only a few salient points, selecting those which are most commonly overlooked or neglected.

The most radical cause of trouble in connection with installation is vibration and the consequent reciprocating motion of the shaft; for this reason the most solid of foundations should be selected, the neighborhood of moving machinery should be avoided, as should also partitions of light construction in which doors are located. The rhythmic vibration of moving machinery is infinitely more dangerous than occasional heavy shocks.

Meters should be installed as near to the foundation as possible, not as is now quite common, at the tops of buildings, where the amplitude of all vibrations is of course much greater.

Locations where great variations of temperature occur are undesirable. For this reason also, basements are preferable to attics.

A very common error, causing the loss of very many meters annually, by the burning out of the potential circuits, occurs in connection with the metering of power delivered to motors. In the effort to save the very trivial amount of energy passing through a potential circuit, it is very common to install meters on the motor side of the controlling switch. This not only exposes the meter to the full force of the field discharge, but it also results in the constant cooling and heating of the potential winding, and the resultant expansion and contraction chafes and weakens the insulation and also weakens the wire itself at the turns, opening the path for a final breakdown either by a lightning discharge or by a field discharge.

As to care of meters. It is a fallacy to suppose, as many insist upon doing to-day, that meters should require no care whatever. Almost all meters will continue operative for a very long period without any care whatever; but the cost of a cleaning and testing visit twice annually is trivial as compared with the good results which follow such a system, by reason of the better light load accuracy obtained. It is not, I think, too strong a statement to say that such a system will have an influence for good, amounting to from 3 to 5 per cent. on the meter readings annually.

Central station managements have probable given more attention to systematic methods of meter reading than to any other one point contributing to success. The old and faulty plan of reading the dials of a meter at the time of the visit to the meter, is fast giving place to the better system, which provides the reader with a fac-simile of the meter dial in blank upon a page of his meter book. This fac-simile is roughly marked in pencil to indicate the position of the hand at the time of the visit. These fac-similes are taken into the office and are all read by one individual who is an expert in meter reading, and who sets down the consumption under the fac-simile on each page. Such a system commonly reduces the errors from about 10 per cent. per month where they not uncommonly stood under the old system, to materially less than 1 per cent. under the new; for surprising as it may seem, it is an extremely easy thing to make mistakes in reading meter dials.

In changing from the old and not infrequently popular contract system, a good many central stations in the earlier days made the grave blunder of going on to the new basis during the winter months, with the result that the highest bills of the year reached the customer after a long period of indulgence under the contract system, and the result at times proved temporarily disastrous.

Even to-day the pernicious influence of uniform bills the year through, which was created by the contract system, still lingers; and the proportion of customers who complain because their winter bills are materially higher than their autumn and summer bills is quite considerable.

It will be said that the explanation is sufficiently simple; but, unfortunately, however good and however simple the explanation, it has proved no simple matter to secure its acceptance and credence. I have lately been much impressed by a system which has recently been adopted by a prominent western company to at least partially offset this difficulty. During the months which are growing darker, they read their meters a day or two earlier each month, thus arbitrarily creating shorter months, whilst as the year progresses to the period of lighter days, the months are lengthened. This somewhat tends to even up the bill, is apparently quite as satisfactory to the customer, and is certainly entirely just and has created a very great falling off in the complaint list, for the character of the complaint keeps pace with the period of the year. Out of the hundreds of complaints which I receive annually, I find that by far the greater proportion in the summer are of slow meters and in the winter of fast meters.

I do not feel that I shall be doing justice to my subject, should I fail to make at least brief mention of the application of meters to the measurement of station output.

The gas companies to whom all central stations look for precedents, long ago found it imperative that they should have some means of determining just how much of their commodity they produced, and sent out through their mains. In all commercial enterprises it is difficult to satisfactorily guide and control a business, unless there be some positive means of determining how much of anything is produced; and it is surely just as important to all electric lighting companies to know how much of their commodity they manufacture as for any other concern. Until quite recently it has not been possible to obtain recording meters sufficiently large to care for the heavy outputs which are now so common, but such meters are now readily obtainable.

The value of a system of station meters must necessarily prove very great, since it furnishes an absolute check system upon coal and water consumption, and engine and dynamo efficiency. Whilst it also furnishes a ready means for comparison between station output, customers meter indications, line losses, leaks and grounds.

In closing, some brief consideration at least is due to the new fields into which meters are reaching, and to the help special metering features may perhaps give indirectly as well as directly, to the amplifying of the business of electric light and power companies and to their more economic operation.

There has recently been much interesting discussion regarding the question of the flattening of the peak of the load either by the systematic modification of rates under special time contracts, governing the hours of burning, which does not concern the immediate subject matter of this paper, or by an actual modification in one of several forms in the meter itself, which should practically make the meter automatically control the modification of the rates in such a way as to gain the same end with certainty, as is aimed at in the special contract system.

Whilst personally I have grave doubts regarding the actual feasibility of this plan commercially, in view of other and perhaps simpler methods by which it can be accomplished, I still have much respect for all of the various methods which have been proposed and do not question that there will be at least many cases where they can be advantageously applied. Questions relating to the peak of the load, however, are subject to such great variations locally that a rule which would apply in New York might very readily fail in a system adopted in a smaller town.

It is quite obvious that the best double-rate meter will be that which tends to flatten the load curve of the station, not by oppressing or discouraging the user of light, who must have his light at the period of the peak, so much as by encouraging the use of light at other periods. We do not want to provide means for cutting off the peak so much as we want means for raising the rest of the curve to the same height as the peak. In my personal opinion, it is in this respect that perhaps the most ingenious of all these double-rate meters falls short. I refer to that form of two-rate meter which proportionately increases its rate of record at such time as the local load which it is measuring is highest. This discourages the use of light at the period of the local peak, and if the local peak and the station peak are co-incident, it absolutely fulfils its purpose. But if they are not it fails, because instead of discouraging the use of a large amount of light at the time of the local peak, it should actually encourage it. Encouragement of local peaks, which are not co-incident with the station peak, is beneficial to the central station in the highest degree, for it tends, as I have pointed out it should, to raise the general load curve towards the station peak magnitude.

If two-rate meters are to be used, therefore, I believe that their increased proportional speed should be dependent purely upon the occurrence of the station peak, and should bear no relation whatever to the occurring of the local peak. Such an arrangement can be secured in a number of ways, all of them simple and all of them effective.

One other feature of metering, which has recently come into existence in Europe, is about to make its appearance commercially in this country. It brings with it much of promise for the increase of profitable business for central stations. I refer to the pre-payment meter system. The drop-a-nickel-in-the-slot and get-your-money's-worth-meter. In gas practice this system has proved an unqualified success. I am informed that the London Gas Light Co. added 6,000 new customers of a profitable kind, over and above their average annual growth in a single year; and other companies have had similar experience.

There is in every large city a considerable area into which illuminating companies have been unable to go by reason of the untrustworthy character of the people who would there be their customers. In other words, because the people in these districts are a floating population without credit, coming to-day and going to-morrow, and yet ready and willing to buy electric light at high rates.

The pre-payment meter throws open this new field and makes it immediately available; and here I predict for it wide usefulness.

DISCUSSION.

THE CHAIRMAN:--[Vice-President Steinmetz.] The discussion of Mr. Haskins' paper is now in order and I call upon Dr. Bell to open the discussion.

DR. LOUIS BELL:—The engineering point of great interest in connection with the subject of meters just at the present time, seems to me to be the problem of metering such loads as one strikes with motors, and especially with fan motors on the alternating system, and induction motors generally. The metering of the direct current as compared with the metering of the alternating current under these circumstances is a straightforward, simple problem, which gives no trouble either to the engineer or the station master. There may be trouble with direct current meters, but they are nothing compared with what are met in trying to measure in a just and reasonable way the volt-amperes energy delivered to the induction motors. As these modern plants are becoming more and more common, the central station man and the meter man may have to unite to find some way out of the difficulty. The trouble is right here: That if you apply an ordinary integrating watt-meter to a circuit having a highly inductive load, while you get paid for the energy delivered, you do not get paid for the capacity of the machine used up. It is a perfectly easy matter to run beyond the capacity of your station on a motor load, while your actual receipts as indicated by an integrating watt-meter would be far below the capacity of the station. Of course, the immediate impulse is to say—use a recording ammeter. But the recording ammeter, as Mr. Haskins has pointed out, scares the average customer. Then, on the other hand, the recording ammeter in many cases punishes too much. You do not care in handling such things as fan motors for a small increment of current due to their power factor; relatively it is a very large increment of current, but absolutely its effect on the station is not very great, because the amount of each motor is small, and the number is generally not sufficient. If you were to charge under these circumstances for current and not for energy, you would run up a bill against the fan motor which would apparently be out of all reason. Fan motors take current generally at relatively the same current as electric lights; that is to say, there is no special rate laid for them. On the other hand, when you come to have induction motors, particularly those which have bad power factors, and their number is great—when you come to these motors the matter gets more serious. You cannot afford to charge simply for the energy delivered, if you have any regard either for the capacity of your station or for the kind of service you are likely to give on mixed loads. Some way must be devised of charging not only for the watts delivered, but for the amount of reserve capacity which has to be set apart for running the motor in question. It is not uncommon, and it is a very unhappy experience to find plants intended for the operation of induction motors simply at the end of their capacity for current, long before the output capacity of the motors has been reached. Those are the cases where the meter man is going to have a hard time. It is a difficult thing to adjudicate, and one which will have to be settled by continual conference between the station man and the meter man. My opinion is that the watt-meter is not sufficient for a case of the kind. You would be compelled to put the rate for the kilowatt hour so high, in order to get fairly paid under those circumstances, that the ordinary customer would kick. It would seem unreasonably high as compared with other motors, and it would be unreasonably high. It seems to me that some method ought to be devised akin to one that has recently been discussed, that is, a two-rate system which charges a basic price for maximum amperes, plus a watt-meter price for energy delivered. A scheme of that kind either carried out by arranging a fixed basic price per month, plus watt-meter price, or the plan which has been tried abroad of charging a certain rate for capacity, a certain fixed price plus a regular price. Either of those plans, either a fixed contract or an automatic plan having a meter to take care of the watt-meter, and some way of automatically taking account of the maximum current—some one of these plans I say must come into use under the circumstances, because neither the straight, ordinary watt-meter, nor a current meter, will fill the bill properly for these cases. If you charge for watts, pure and simple, you scare the customer. If you charge by amperes, you scare him even more completely and thoroughly, and as far as I can see the only satisfactory outcome for both parties is going to be in settling on some sort of double arrangement for the particular kind of service. I speak of it with special interest because that kind of service is growing every day, and it is the only example where metering does not seem to fit the case as well as it should. In passing—I believe as regards the character of the meters that we are going to have, that the biggest improvements, so far as the ordinary customer is concerned, speaking purely from the customer's standpoint, are the meters which I think will come into use before long which read directly so-and-so many watt-hours recorded in figures on the dial. Anybody who has ever tried to read an ordinary dial meter, not being familiar with it, will realize the position of the ordinary customer when he sees this queer thing spinning around on the wall, running up he knows not what against him. He looks at it as something uncanny, and he believes if Solomon lived in these days he would say: "Go to the meter thou sluggard."

Dr. Perrine:—I want to call especial attention to what Mr. Haskins says about what is to be considered as the range of voltampere accuracy of a meter. That we should not look for starting ability at extremely low load, and accuracy at full or maximum load, but that meters should be installed as small as possible, which would give accuracy on overloads; a fair accuracy on overloads and very great accuracy on a small *ordinary* load; for I think that this is a principle that has been too little insisted upon, in general central station engineering practice, not simply in the question of meters but in the choice of engines, boilers, dynamos, transformers and every piece of apparatus about a station. Of course our engineers are working up to that more and more; but nevertheless it is a point that cannot be insisted upon too strongly, that real and true efficiency in the station is to be obtained by working our units always at a comparatively high load and high efficiency, installing apparatus which will stand overloads so that they will give high efficiency at the ordinary load at the station. This I have found in very many instances singularly neglected in central station practice, and we see its effect in the report of the National Electric Light Association. I have not seen their last report of coal economy, but that which was issued about a year and a half ago, shows that the best central stations in this country were using about three pounds of coal per horse power hour, and that the average throughout the country was not very much better than about five pounds, and some of the good stations run up to eight or even more pounds of coal. This, in the face of the fact that the dynamos are all of high efficiency; that in the electric central stations there are the best engines that the skill of the country can afford, and that in no one of those stations would machinery be accepted which would not give on test a better efficiency than two pounds of coal per horse power hour. But test means, test at full load, whereas running means running at a quarter or less than a quarter. Now it seems to me that in the case of all of our machines, not simply in the case of meters, but in the case of meters as well as in the case of other machinery, the machinery should be chosen where the full load is below the maximum load at which it is capable of running, and that in consequence, in place of machinery running at normally low loads with low efficiencies, the lightest loads should still be loads sufficiently great to give good efficiency. I was very glad to see that Mr. Haskins so well recognized this point and I think that its clear understanding and enforcement is one of the things that engineers need in order to bring up the general efficiency of their work.

PROF. OWENS:—I would like to ask Mr. Haskins if he considers that a meter which is correct on light steady load and also on full steady load would be accurate on rapidly varying loads?

MR. HASKINS:—Replying first to Prof. Owens' question, my experience has commonly been that a meter that will give accuracy at light load, and will give accuracy at high loads, will almost invariably be a good meter on intermittent loads.

PROF. OWENS:—How do you determine its accuracy on rapidly varying loads?

MR. HASKINS:—The method I have generally used for determining accuracy on varying loads has been to use a master meter, arranging two of the meters exactly alike and in multiple, but in series with a third or master meter, using a special form of switch between the master meter and the other two meters, so that the load could be rapidly switched through one or through the other or in multiple between the two, never off both of them. Then having achieved such an arrangement as that, I have hours at a time kept a boy or some one moving that switch, changing the load from half load to no load, from half load to full load, always passing through one or both of the two quantities under test and under all circumstances passing through the master meter, the load being constant on the master meter. I think that is perhaps the most accurate method of determination. I think I may say that my average experience while using this method has been less than one per cent. error, commonly within one-half of one per cent. It is a method I have used repeatedly and I have found it very satisfactory.

Referring to what Dr. Bell has said, I agree heartily with him and I think we can look far enough into the future to see that another form of two-rate meter is going to be called for, a meter whose rate of recording shall be dependent on the power factor. I think I am safe in predicting that when the demand comes, we can promise a meter which will automatically vary its rate with the variation of the power factor; this I think will be the simplest way of solving the problem. The use of the ampere-meter not only has the effect of discouraging the customer, as Dr. Bell says, but of discouraging one's own business. Referring to Dr. Bell's other suggestion that the general way of reading meters to-day is trying, I would say that I think the time has come when we can afford to have the customer read the dial easily. I think that within a short a time direct reading device will be procurable, but expense is the limiting factor in all these things. Such a dial as that is inherently more expensive, and people do not want to pay more for their devices.

PROF. OWENS:—Would not the addition of the so-called Wright-Demand meter to the circuit containing a watt-meter solve this question of variable power factors?

MR. HASKINS:—Yes, I think it would. I think that perhaps is one of the best applications of the Wright-Demand system. The only trouble with the Wright-Demand system is that it does not segregate idle from active currents. If we had a combined load of light and power it might be conceivable that the maximum current was due to legitimate energy. I think that the Wright-Demand system would solve it admirably except for this consideration, which perhaps is not very important, but not so simply as a meter which would automatically and within itself change the rate, supposing such a meter were available. It is not available to-day, but it does not look like an impossible problem. I want to thank Dr. Perrine for his endorsment of my views. As to the question of capacity I think that the great mistake that everybody has made, more particularly in metering and probably in our other devices also, is to demand laboratory instruments for commercial use. They want a meter that will give phenomenal accuracy on phenomenally low loads, ignoring commercial conditions. Meters twice too large are frequently put in, so that when the output increased they would be big enough, and yet phenomenal accuracy on light loads was demanded from those same meters, accuracy which injured the meter and made the meter too sensitive. It was like putting a laboratory instrument into common use.

MR. H. C. SPAULDING:—The remarks which have been made about the desirability of meters which allow direct reading by the customer and which should be cheap and practically free from liability to tampering, all had a bearing on a system which I have sometimes felt could be used to great advantage on ordinary power work, especially where the motors are in small units, as a modification of the old contract system where the representative of the company would squint at the pulleys and belts and do a little figuring in his note book and then make a contract for about 300 per cent. profit over the actual estimated cost of current. Those days have gone by, fortunately for some; but it would seem to me that on small motors and to a certain extent larger ones, it would be perfectly feasible to have a register which should so record that the motor could be charged for simply by the hour. That has been tried in some cases and I understand with very satisfactory results. The central station man can probably get more money for his current than he would with a watt-meter. The customer on the other hand knows that every hour that he uses his motor, it costs him just so much, this register being read at the end of the month precisely as on any ordinary meter, and he pays for so many hours use of the motor, the rate being made on what can be very reasonably judged as the average probable current consumption which it is fair to get at for an hour, but rather doubtful when you come to multiply that by 300 days in the year.

MR. A. E. CHILDS:—I would like to ask Mr. Haskins a few questions with regard to this slot meter which he has brought forward, as to whether he has any figures as to its use in this country and as to whether it has been successfully and satisfactorily used in Europe. The size and weight and cost are questions I would like to hear about too.

MR. HASKINS:—Replying to the last speaker, I have not any absolute figures on American practice. I think that American practice is very new, and what figures are available have been kept for the use of the initiators of the system. The system has been very widely used in London and has spread, I believe, to some four or five other large cities in Great Britain. I believe continental practice is somewhat slower and is behind that of

Great Britain. In a gas meter I understand that the extra cost is about 30 per cent. of the whole. I would add that the rate charge is something more than 30 per cent. higher The weight of the gas meter, and it is almost entirely limited as yet, to gas practice, is not materially increased. While I have not any positive figures I think I would be safe in saying that the weight is not increased more than about 15 per cent., it as much. The method of operation varies in the different devices. The whole thing might be compared to a chewing gum machine such as one sees on the elevated railroad platforms. It is common to have a slot for coins and some kind of an actuating movement, either in the shape of a slight push rod or crank which does the mechanical work, and most of these devices are deficient in that they commonly permit the deposit of only one coin at a time. You have got to use up the value of that coin before you can deposit any more.

Referring to what Mr. Spaulding said I think there may be some applications for what he mentioned. I believe that such a device was offered in the market for some time about two years ago. It was made in the west. It is better than the contract system, but it is not metering. Not *a propos* of what Mr. Spaulding said, though it is suggested to my mind by it, I want to tell a story. I had some connection some time ago with a young man who was engaged in meter testing. He had previously appealed to me for a ready method of testing motors in connection with meters, and I supposed that I had given him one, but he passed out of the employ of the firm with whom he was, and they kept his note-books. One day they brought me his note-book remarking that they saw noted under my name a method of testing meters with motors and wanted to know if it was right. It read like this—reminding me of what Mr. Spaulding said about squinting at a shaft—"Estimate the horse-power of work being done by the motor, and test the meter by the common formula. If the results agree within 10 per cent., all right, if not, estimate the motor again."

THE CHAIRMAN (Mr. Steinmetz):—Gentlemen, I fully agree with Dr Bell that it is very desirable to have some means of charging for the wattless currents in alternating current circuits. It is not fair to charge a customer by ammeter for all the wattless current he uses, especially as you would not keep any customers in this way. It is not fair, because this current does not represent power to the customer or to the central station. However, it is not fair either to charge by watt-meter, because you then do not charge for those wattless currents which do represent power as loss in lines and transformers and wasted station capacity and thus interest charge. Therefore it would be desirable to charge for a part of the wattless currents, a part sufficiently large to take care of the losses due to resistance of lines and transformers and generator capacity. It is very easy to do that with the recording watt-meter. The only thing necessary is to replace a part of the non inductive resistance of the potential coil by reactance. Assume that we insert in the armature or potential circuit of the recording watt-meter an inductive reactance equal to 20% of its impedance, reducing the resistance correspondingly, so that the meter reads correctly at non-inductive load. On a highly inductive load, of 20% power factor or so—as the current of an induction motor running light—the meter will read just twice the power or will read about one quarter of the wattless current. That is probably a very fair charge. You may make it anything you want by varying the self-induction. Such meters are in operation, but there is one difficulty with them, as you can see, not on the electric side of it indeed, but you cannot supply such meters except on special request, because if you supply such a meter, which is an entirely fair and proper meter to use, then somebody tests it under highly inductve load and finds the meter 100 per cent. wrong. The next thing you hear is, it appears in some paper, that the meter is entirely wrong and unreliable on inductive load. Thus you can only build such meters on special request. Now it is necessary to take some steps like this, especially where the motors are supplied by the customer; otherwise the customer buys some cheap kind of induction motor with a horribly low power factor, or at least installs a motor by far too large for the work to do, and runs it very light most of the time—that is at poor power factor—causing wattless current of excessive value to run all this time over the circuit without being charged for but using up line and station capacity.

There is one point in the paper on the wave-shape which is very interesting and where something more can be said. The meter should be correct for different wave shapes. For not only with different machines but even with the same machine on a different load, the wave shape of the circuit may change, not if you have lights in circuit only, but if you put in any inductive device, say a fan motor or reactive coil. The current wave consumed by the fan motor essentially differs from the wave of the electromotive force, and consequently there are current meters which read wrong in such cases and cannot give accurate reading. On a fan motor load some current meters read low, and some one told me, in all apparent truth, that if he had several lights running on a meter and leaves the lights on and puts a fan motor in besides, the meter slows down. I don't know whether that is not exaggerated, but there is decidedly a lag in the meter to read fan motor current. More vicious probably than the fan motor current is the current taken by the high frequency sets to produce X-rays, because thereby the secondary current, of the condenser discharge, is oscillating, and the primary current is decidedly affected thereby and broken up, so that it is quite likely a very large current may flow and the meter not take any notice of it. The watt-meter is much less liable to this difficulty. The only error in a watt-meter may be due to very rapid oscillations which may not be recorded, but which are not very likely to occur.

MR. HASKINS:—In regard to what Mr. Steinmetz said in connection with the slowing down of meters by throwing on additional load, I would say that I have met such meters and tested them. Out of the west there came a story that a certain kind of meter (which by the way is not now obtainable), was in one town commonly reversed and backed up daily by a customer who ran it on his lights normally, and who, when he was not running his lights, put a special form of choking coil onto a lamp socket, thus backing the meter up. He generally backed it up long enough to nearly cancel what it made running ahead. I should scarcely care to absolutety vouch for this report however.

[Recess.]

EVENING SESSION—TUESDAY, JULY 27TH, 8.15 P. M.

The meeting was called to order by President Crocker at 8.15 P. M.

THE PRESIDENT:—Before proceeding with the business of the evening, I have to announce that to-morrow morning, after the first paper, Prof. Owens would like to present an invitation to the INSTITUTE to come to the Trans-Mississippi Exposition next year to hold the General Meeting, and I will also make an informal report to the INSTITUTE as to the adoption of the "National Electric Code." The first paper on this evening's programme is "A Historical Sketch of the Fire Alarm Telegraph" by Mr. Adam Bosch.

SECRETARY POPE:—I wish to call attention to the fact that the original signal box referred to in Mr. Bosch's paper, also the second form which followed it, and the third, are on exhibition in the collection of Mr. Farmer's inventions.

A paper presented at the 14th General Meeting of the American Institute of Electrical Engineers, Eliot, Me., July 27th, 1897, President Crocker in the Chair.

HISTORICAL SKETCH OF THE FIRE ALARM TELEGRAPH.

BY ADAM BOSCH.

On June 3d, 1845, the *Boston Advertiser* published a communication by Dr. W. F. Channing, in which public attention was called to a new application of the telegraph, in these words: "There is a highly important application of the Electric-Magnetic Telegraph to which public attention has not as yet been directed. This is its use in our cities, to give an instantaneous, universal and definite alarm in case of fire. The peculiar properties of the telegraph—rapidity and precision of communication—are, in this instance, preeminently needed."

The writer then goes on to unfold his plan, substantially as follows: A central office was to be established in some public building, in which the necessary battery, together with a Morse register and an alarm bell, should be located; a double wire to proceed from thence over the housetops successively to every engine-house and fire bell in the city, and return again to complete its circuit to the place from whence it started. In every station thus established, a Morse register in connection with an alarm bell was to be placed, also a key, by the simple depression of which an appropriate signal would be instantly conveyed to every other station on the circuit.

He also suggested the modification of having five or six circuits, or even a circuit from every station, to the central office. By this method the operator would be able to communicate directly to all the stations, and, if so desired, every alarm of fire might be made to pass through the central office before being communicated to the different stations. From among the many modifications to which his design is susceptible, Dr. Channing calls special attention to one, in these words: "There is, however, one which deserves to be specially mentioned. By a slight change of the arrangement at the alarm-bell stations, and increase of machinery, the hammers of the bells could all be disposed so as to strike mechanically on the communication of a galvanic impulse from the central office. The agent (operator) would therefore be enabled, by depressing a single key with his finger at certain intervals, to ring out an alarm defining the position of the fire simultaneously on every church bell in the city." This description clearly indicates the electro-mechanical bell striker, which had not yet been invented. In conclusion, Dr. Channing urged the municipal authorities to take his project into consideration; and, as the city had been behindhand in the matter of giving alarms of fire, the adoption of this system would place her in advance of other cities.

The next effort to apply the telegraph to fire alarm purposes was made in 1847, by F. O. J. Smith, who was at that time in charge of the Morse telegraph interest in the New England states. Mr. Smith consulted Moses G. Farmer, whom he considered one of the foremost electricians in the country, as to the possibility of striking a number of large bells simultaneously by means of electricity. Farmer agreed to produce an apparatus by means of which this could be done, and in a short time exhibited to Smith a model of his invention, the simple and beautiful piece of mechanism which afterward became well known as the falling ball electro-magnetic escapement. This was substituted for the mechanical escapement on a church-clock striking apparatus in common use at that time. Mr. Smith was highly pleased with the apparatus, and immediately submitted a plan for establishing a fire alarm telegraph to Josiah Quincy, Jr., Mayor of the city of Boston. This plan proposed connecting 15 engine-houses by telegraph, and equipping three large bells with electric-bell striking machines, the same to be operated simultaneously from some convenient point. Mayor Quincy, in his annual address, January 3d, 1848, recommended this subject to the consideration of the Board of Aldermen, which body acted on this recommendation to the extent of ordering two bell-striking machines for the city. They were made under the direction of Farmer, and, when completed, submitted to a public trial, which proved very satisfactory. After this the city authorities took no further action in the matter, and Mr. Smith abandoned the subject.

Early in the year 1851, Dr. Channing, who had, in the six years since the first publication of his plans relating to the establishment of a fire alarm telegraph, spent much time and thought in his endeavor to shape public sentiment favorable to his project, sent an elaborate and well considered communication to the Mayor and Board of Aldermen of the city of Boston, commending his fire alarm system to their consideration, accompanying this communication with diagrams of the proposed signal and alarm circuits, a map showing the division of the city into six districts, a description of the apparatus required, an estimate of the probable cost, and also an offer to give a practical exhibition to demonstrate the feasibility of the system, if desired. The general outline of the system as proposed was as follows:

The city was to be divided into six fire districts. Three signal and three alarm circuits were to be constructed. To avoid possible interruptions of the circuits, all wires were to be run double. The ground was not to be used as any part of the circuit, for the reason that unauthorized persons might complete the circuit by establishing connection between the wires and the ground. The whole of the machinery of the signal stations was to consist of a signal key, locked in a small box.

The central office was to be located at the City Hall, and the apparatus to consist of a receiving magnet (relay) on every signal circuit, and a local circuit to operate a register and alarm bell. For an apparatus to transmit alarms to the large bells, the employment of an instrument moved by clockwork, then well known in connection with the Morse telegraph, was suggested. This consisted of a cylinder made of wood, having a metal core, over which a number of keys fashioned like piano keys were arranged, and under each key, strips of metal in groups, were fastened to the cylinder and connected with the core. When this cylinder was set in motion and one of the keys depressed, a spring would bear on the cylinder, and, if properly connected, a signal was given corresponding to the number and position of the metallic strips under this particular key. It was in connection with preparations for the proposed exhibition previously mentioned, that Dr. Channing made a search for the two models of bell-striking machines made in 1848 for the city. He found them stowed away in a lumber room, and covered with dust.

He had himself devised an electric escapement for bell-striking machines, but he quickly recognized the great superiority of the one invented by Farmer, and therefore decided to use the models in his public demonstration. Desiring to obtain the inventor's assistance at this exhibition, he sought an interview with Farmer, who readily consented. At this meeting they agreed to join their interests and co-operate in all matters relating to the establishment of a fire alarm telegraph. An exhibition was soon given before the Mayor and Board of Aldermen, at which Farmer assisted. It proved highly successful, and resulted in an appropriation of $10,000 by the city government for the purpose of carrying out the proposed plans.

At the urgent request of Dr. Channing, Farmer was appointed Superintendent of Construction. He entered upon his duties at once and with characteristic energy. The task before him was not an easy one. "Something new under the sun" was about to be established. For months nearly all the work was experimental; apparatus was constructed and discarded as defects manifested, or improvements suggested themselves.

In the construction of the signal boxes the first departure from the original plan was made by adding a wheel and crank to opperate the key. This wheel had certain definite projections upon it, their width and position varying with the signal to be conveyed, the wide projections being for dashes, the other for dots. On turning the crank each projection on the wheel would in its turn open the key, and keep it open for a longer or shorter period of time according to the width of the projection. The handle of the crank was weighted for the purpose of maintaining the wheel in its normal position where none of its projections were in contact with the key.

It was soon discovered that considerable skill was required to operate this device with any degree of regularity; the motion of the crank in unskilled hands was so irregular that the signals could not be distinguished as printed by the register. This was therefore discarded, and other apparatus constructed with the same break-wheel, but the crank was so arranged in connection with two gear wheels that two revolutions of the crank were necessary to produce one revolution of the break-wheel.

Considerable trouble was also experienced in the point of contact of the signal keys. This was remedied by substituting a sliding contact. In the original plan the signal box was designed simply to transmit the number of the district in which it was located. The improved apparatus also gave the station number; the district number by dots, and the station number by dashes and dots; this added greatly to its value as a means of indicating the exact locality of a fire.

But the most radical departure from the plan was made by placing the signal boxes on the outside instead of the inside of buildings as originally intended; this change necessitated better protection for the apparatus. This was effected by placing the iron case which contained the mechanism into a strong iron box, in form similar to the one in general use for that purpose at the present time.

If the difficulties encountered in the construction of the signal box apparatus were great, those met with in the construction of the bell-striking machines were gigantic. Farmer's original models were made to strike bells weighing from 75 to 150 lbs., and now 19 machines were to be built to strike bells weighing from 300 to 3700 pounds.

It was necessary that all the bells whether large or small should be struck successive blows in the same short period of time, and, to satisfy the public, that they should be struck with a force no less than that by which they were formerly struck by means of rope and tolling hammer. To accomplish this, weights of from 800 to 2000 pounds according to the size of the bell to be struck were found to be necessary. Every point in connection with these machines had to be determined experimentally. It was a problem without any known factors. Machines were built, tried and discarded. For the largest sized bells three machines were built before one was found to answer the purpose.

Locality had to be considered. In some of the belfries the space for the machines was ample, in others it required various modifications of the apparatus in order for it to be properly placed. What added greatly to the perplexity of the situation was the fact that all the experiments had to be made in public. To test the machinery it was necessary to strike the bells, and, it is therefore not to be wondered at, that complaints about the incessant clanging of the bells were heard all over the city. The citizens were far from being unanimous in favor of the experiment. The man who knows it won't work, as well as the man who knows that even if it does work it won't be as good as the old method; both resided in Boston at that time as they reside everywhere, where important improvements are about to be made. Dr. Channing who was a charming writer, wrote many articles for the daily papers in order to create a stronger public sentiment in favor of the experiment.

As in the original plan the apparatus furnished for the central office consisted of a cylinder transmitter or key-board as it was called, very much improved; the keys were so arranged that simply depressing one of them would liberate the clockwork and start the cylinder, and upon releasing the pressure it would come to a stop in its normal position. In order to economize battery power, three metal springs were placed on the underside of the keys. Each spring was connected with one of the three alarm circuits and so arranged that as the cylinder revolved, each metal strip on its surface would make connection with each spring successively, thus allowing the same battery to be thrown on each one of the three circuits in quick succession.

For the Morse register to be used in connection with the alarm circuits to indicate the number of blows struck on the bells, an indicator was devised consisting of three revolving cylinders on which the numbers were exhibited in large plain figures.

On another instrument not mentioned in the original plan but very useful and important was an automatic circuit-testing clock which tested the circuits once every hour.

In the spring of 1852 the system was so far completed that it was deemed sufficiently reliable to submit it to public use. Nearly a year had passed since the work was begun. The time required as well as the cost, far exceeded the original estimates. The $10,000 appropriated at the beginning was spent long before the work was completed, and a further appropriation amounting to nearly $6,000 were found to be necessary. This was caused partly by the extraordinary difficulties encountered, and partly by the extension and improvement of the system beyond the requirements of the original plan. Thus instead of 26 signal stations, 39 were established.

April 28th, 1852, was decided upon as the day on which the new method of giving alarms of fire should go into effect. That there was considerable misgiving concerning the reliability of the new system, and which, as the result showed, was not altogether groundless, the following extract from the printed directions issued before the telegraph went into use will abundantly show:

"Before giving an alarm be sure that a fire has occurred within "your district; being reasonably certain of that, turn the crank "within the box, say ten times, not too fast, and wait. If the "signal is perfect, you now have registered at the central office "the number of your district, as well as the number of your box. "If the alarm is heard at the central office, the operator there "will indicate the fact to you as soon as you have ceased, by "striking the number of your district with the small magnet in "your box, twice at least. Should you not hear this, turn the "crank again, more slowly. Should you not then hear the "response, go to another box, and if equally unsuccessful there, "carry the alarm yourself to the central office"

That the latter injunction was not unnecessary is evinced by the entry in the Journal of the Central Office, on April 29th, the day after the telegraph was given over to public use, thus, "First Alarm, 8.25 P. M. from Station 7, District I, J. H. Goodale turns the crank like lightning could not read; brought alarm to office." In this case the register failed on account of the great speed with which the signal was sent. During the striking of this alarm on the bells, four machines were disabled. For many months after the system went into operation, serious defects were continually developing, and a time of great anxiety for its projectors ensued. Farmer and his assistants, in ceaseless activity, spent day and night modifying, improving and adjusting apparatus. The alarm bells were a source of the greatest trouble and anxiety; their failure to strike correctly encouraged the opposition to the system to renewed effort in which, strange to say, the firemen were most prominent. But gradually, by unremitting exertion difficulty after difficulty was overcome, and by the end of the year a reasonable amount of confidence was felt in the reliability of their performance. Another cause of anxiety, especially to the operators at the central office was the irregular manner in which the crank was often turned, giving an alarm from the signal boxes; some persons laboring under intense excitement would whirl it around with a speed that fairly defied the register to print the signal; others, mindful of the instructions to turn slowly, would turn the crank with such exaggerated deliberation, that it required a long investigation on part of the operator which was not always successful, to distinguish dots from the dashes. On January 1st, 1852, in view of the early completion of the work, and in order to retain his services for the first few months of its practical operation, the Board of Aldermen had elected Farmer superintendent of the new system for a term of six months. It was generally conceded that no one else could make it a practical success. The friends of Farmer who urged him to accept the position, deemed it of the utmost importance that the experiment should be made a success from the beginning, as a failure at that time in Boston would be fatal to its introduction into other cities. Farmer accepted the position, but instead of six months, three years passed before he considered the system in such a condition that he might safely place its management into other hands.

The first city after Boston, to adopt the fire alarm telegraph was Philadelphia, where it was introduced in 1855.

In 1855, Dr. Channing, who had done much to bring the subject of the fire alarm telegraph before the public and city authorities, delivered a very interesting lecture before the Smithsonian Institution. It was through this lecture that the attention of J. N. Gamewell was first directed to the fire alarm telegraph. On the occasion of a visit, Professor Henry called his attention to the lecture and presented him with a copy. Immediately after its perusal he started for Boston and acquired the rights for the southern and western states.

The fundamental patent covering the invention of the fire alarm telegraph, as exemplified by the Boston system, was granted to Channing and Farmer, May 19th, 1857. Another patent was issued to them in March 8th, 1859 for a repeater.

The following patents relating to fire alarm telegraph apparatus were granted to Farmer alone.

May 4th, 1852; Electro-Magnetic bell striking apparatus.

Jan. 11th, 1859, for an improved signal box, in which the magnets were shunted by the closing of the outside box door, a practice that has been followed up to the present day.

February 22nd, 1859 for an automatic system in which the central office is dispensed with, and the signal boxes and alarm bells are all placed on one circuit, and where consequently, when an alarm of fire is given, all the bells will strike instantly and simultaneously, without the aid of an operator. This was called the village system, from its adaptability to small places, where the expense of a central office would be prohibitory.

Two other patents were granted to Farmer in 1859. One was for an "electric-magnetic apparatus for setting water motors in motion." This was applied, for a short time, to operate some of the bell-striking machines of the Boston system in place of weights. The other patent was for "Mechanism for operating signal whistles by electro-magnetism."

A very important improvement was made in 1856 by Chas. T. Chester, to whom a patent was granted for an "automatic electrical circuit breaker." In this apparatus the break-wheel was moved automatically by means of clockwork actuated by a spring. Although this particular apparatus never came into public use, it is practically the first automatic signal box of which we have any knowledge.

After three years of agitation and hard work, Gamewell and Company met with their first success in the city of St. Louis, where they installed a plant in 1858. St. Louis was, therefore, the third city to adopt the fire alarm telegraph.

In 1859 the same firm obtained, by purchase, complete control of all patents relating to the fire alarm telegraph granted to Channing and Farmer, or to Farmer alone. Mr. Gamewell early recognized the fact that a fire alarm telegraph having one of its most vital parts, the signal box, constantly exposed to the elements, to the heat of the summer and to the cold of winter, to rain and to dust, unused until an emergency arises, and where a failure of the apparatus to properly operate in that emergency might result in the destruction of property to the value of millions and even in the sacrifice of human life, should have the best apparatus that ingenuity could design and the highest skill execute. With this object in view, he soon gathered around himself men of inventive genius and great mechanical skill, three of whom especially distinguished themselves by inventions of the greatest merit. These are Edwin Rogers, James M. Gardiner and Moses G. Crane, three names inseparably connected with the development of the fire alarm telegraph. One other name should not be forgotten, that of John Polsey, to whose superior mechanical skill much of the early success of the fire alarm telegraph is due.

The first fire alarm system, equipped with automatic signal boxes was introduced into the city of Mobile in 1866. This was an automatic system, but, unlike Farmer's village system, in which all the apparatus is placed on one circuit, four circuits were provided. This had never been attempted before, and to make it possible in this case, a new apparatus had to be invented, by means of which a signal from any one circuit would be automatically transmitted to every other circuit, and which would mechanically close every other circuit, should any one circuit remain open. This was accomplished by Edwin Rogers, to whom a patent for the first automatic repeater for fire alarm purposes was issued in 1870.

The original crank signal boxes remained in service in Boston until 1866, in which year automatic boxes were substituted in their place. The following year, Joseph B. Stearns, the immediate successor of Farmer in the superintendency of the Boston fire alarm telegraph, received a patent for an apparatus operated by "reverse currents," which permitted the simultaneous use of the same wire for receiving a signal from a box and transmitting it to the alarm bells. Several years prior to the introduction of automatic signal boxes, Stearns abandoned the method of striking the district numbers on the bells, and new boxes were designed to strike the box numbers only. While, with the adoption of the automatic signal box, the speed with which a fire alarm box was operated, no longer depended on the temperament or mental condition of the person giving the signal, a proof was soon furnished that, in a matter of this kind, as little as possible should be left to the intelligence of the public. Incorrect signals were often received from these boxes, for the occurrence of which no cause could be assigned. It was usually the first "round" that was found to be wrong. This remained a puzzle until the cause was discovered, which was this—that the person giving the alarm, disregarding the instructions to "pull the hook down once and let go," would, after the first pull, by way of emphasis, give the hook another pull or two. This would momentarily suspend the movement of the break-wheel, and if it occurred between two successive breaks, a long pause would ensue, and the signal would be either unintelligible or a number entirely different from the box number would be transmitted. For inventions to remedy this difficulty, two patents were issued in 1869 for "non-interference pulls," one to Stephen and Chas. T. Chester, and the other to Edwin Rogers and Moses G. Crane. In the former invention, the arrangement was such that, after the box was in operation, the hook could not again engage the mechanism until the full number of "rounds" were completed; in the latter, the mechanism could be engaged after each full round.

There was however another interference of a very serious nature which often resulted in trouble and delay; this was the interference caused by pulling a box while an alarm from another box was in process of transmission. It is not a very unusual occurrence to have two or three boxes pulled for the same fire, and if these boxes happened to be on the same circuit, and the second was pulled before a full round of the first box was completed, a mixed alarm was the result. In such cases it was usually, but not always possible to obtain the correct signal from the last round of the second box.

The first patent for a non-interference box was issued to J. N. Gamewell in 1871. This is a normally wound box (all other automatic boxes were either actuated by weight, or if by spring were pull wound) with trigger pull, and a so-called skeleton break-wheel, that is, a wheel which in its revolution will keep the circuit open for the greatest length of time consistent with the proper transmission of the signal. It also contains an electro-magnet, and an armature which when it is in a position away from the magnet, shunts the break-wheel. If the box is pulled while the armature is in its normal position against the magnet it is held there by a simple contrivance until the signal is completed. If a box is pulled while another one is in operation, the same contrivance will hold the armature in a position to shunt the break-wheel of the second box during the time of its operation, and therefore no interference can take place. The only chance of an interference lies in the possibility that the hook of the second box should be pulled the instant the circuit is closed, and the armature held close to the magnet, but, as owing to the construction of the skeleton break-wheel these periods of contact are exceedingly brief the chances of an interference are very remote.

In 1880 J. M. Gardiner received a patent for a non-interference signal box which on account of its great simplicity and mechanical perfection has maintained its great popularity to the present day. In this box, non-interference is not effected by shunting the break-wheel, but by a very simple method the box pulled while another box is transmitting its signal is rendered mechanically inoperative. This is accomplished in the following manner. A small electro magnet in connection with the clock-work has an armature with a wide range of movement, so that when fully withdrawn by a retractile spring it is beyond the attractive force of its magnet. An extension on this armature carries a small movable disk. This disk when the armature is in its normal position drawn to the magnet, takes a position between the detent of the movement and the starting lever. If, while it is in this position the box is pulled, the starting lever raises the disk which in turn raises the detent, and allows the clock-work to start. A stationary pin on the outside door restores the armature and holds it close to the magnet whether the circuit is open or closed. The skeleton break-wheel is also an essential feature of this box, and consequently during the entire transmission of a signal the circuit is never closed longer than a small fraction of a second at one time. If while a signal is being transmitted an attempt is made to pull another box the following will take place. Before the door of the box is opened an inch, the restoring pin will be withdrawn and the armature becomes free to recede, and before the door can be entirely opened and the hook pulled it will be withdrawn, together with the disk, but without the disk interposed between the starting lever and detent the movement cannot be started.

One of the most effective remedies proposed for preventing the interference of signals, is the system of interlaced circuits for which J. N. Gamewell received a patent in 1875. In carrying out this method the circuits are run in such a way that no two adjacent boxes are on the same circuit. This is most easy of accomplishment in cities occupying a long but narrow territory. In cities less favorably situated the great amount of wire required to fully carry out this principle has been a bar to its general adoption. An additional advantage derived from interlaced circuits is this, that in case of an open circuit no two adjacent boxes will be out of service at the same time.

If two signal boxes of the non-interference type are pulled about the same time, the one that has precedence by as much as the fraction of a second will transmit its signal, while the other will be inoperative. To prevent the loss of this signal, John J. Ruddick invented a signal box in which this is accomplished in a very ingenious manner. With these boxes in circuit any number may be pulled at the same time, and all will respond successively. While this would be an advantage in the extremely rare cases where two boxes on the same circuit are pulled at the same time for two different fires, it would be a positive disadvantage in all other cases where a number of boxes are pulled for the same fire, to have the circuit occupied transmitting unnecessary signals, should the firemen upon their arrival at the fire find a special call, or a second alarm necessary.

A problem which has not received an altogether satisfastory solution, is how to make the signal boxes readily accessible to any one in case of fire, and in a way that will not at the same time render it easy to give false alarms.

For this purpose a keyless door on fire alarm boxes has been somewhat extensively used in the larger cities; these doors are simply closed by a latch and opened by a handle. On turning the handle to open the box, a concealed gong starts to ring loudly and thus attracts attention; this device answers very well for a densely populated section of a city, but in the sparsely populated portions, its benefit is not so apparent. Many cases are also on record where persons who opened such doors with the intention of sending in an alarm, failed to pull the hook, being under the impression that the striking of the gong was an indication that the signal was being transmitted.

Other methods, such as placing the key in a small box with a glass front easily broken, and located conveniently to the signal box, or over the key-hole with the key permanently inserted therein, have been tried with more or less success.

A traplock on the doors of signal boxes with keys numbered and the holders name registered, and where consequently a key in the hands of a malicious person can be used but once, has been found very effective in reducing the frequency of false alarms.

In one of the most original plans proposed, the boxes are placed inside of booths with mechanism so devised, that upon pulling the hook, the door of the booth will close and hold the person giving the alarm a prisoner until released by the proper authorities.

In another invention, for which a patent was issued, the booth was dispensed with, but instead, the box was provided with hidden mechanism which when released by pulling the hook, would firmly clasp and hold the wrist of the person sending the alarm. For reasons obvious to everyone but the inventors, neither one of these inventions ever found its way into public use.

A not inconsiderable share of the unreliability of the fire alarm telegraph in its earliest stages must be ascribed to the source which supplied the electrical energy. The Grove cell then used was not well adapted for service on a fire alarm telegraph, where uniformity of current strength is such an essential requirement. The Daniel cell, by which it was succeeded, was much more satisfactory, and was generally employed up to the year 1871, when the Callaud or gravity cell was introduced. The superior merits of this cell were soon recognized, and in a very short time every fire alarm telegraph was equipped with it. For over twenty years it was the only cell used for this service. Within the last two or three years, however, it has been superceded in a number of places by the storage battery, with very satisfactory results.

In one instance the gravity cell has been replaced by the dynamo. Superintendent Brown Flanders, of the Boston Fire Alarm Telegraph, about five years ago, applied the dynamo current to a single circuit. Its application was gradually extended, and at the present time the entire plant is operated by dynamos.

The automatic repeater invented by Edwin Rogers was gradually improved by him, as well as by the labors of J. N. Gamewell and Moses G. Crane, until it has become an apparatus of almost absolute reliability. While a signal from any one circuit attached to this repeater is being transmitted, all the other circuits are mechanically locked out, and thus confusion is prevented should a box on any other circuit be pulled at about the same time. It is also provided with a device whereby the armature of the operating electro-magnet is mechanically restored after each break of the circuit, and little more, therefore, is required of electricity than that it should hold the armature in position; consequently it will perform its functions successfully under greatly varying conditions of current strength, a very important consideration in an automatic system, where constant attention cannot be given to the care of the battery or the adjustment of the apparatus.

The electro-mechanical gongs have also been greatly improved, and nearly all are provided with armature-restoring devices, and for the use of fire departments, where the men are not permanently in their houses, they are provided with indicators which expose the number of the signal in large figures.

The general plan of a modern central office fire alarm system still resembles that outlined by Dr. Channing, fifty-two years ago; but, in the instruments and apparatus used, most wonderful improvements have been made.

In the modern central office, the Morse register has been replaced by the multiple pen register, which has the merit of greater compactness, and may accommodate both the signal and alarm circuits, with this advantage, that, as the records are printed in parallel lines on the same paper, their relative positions will indicate, to a second, the time elapsed between the reception of the signal from the box and its transmission to the engine-houses; it thus also incidentally serves as a record of the degree of promptness with which the operator has attended to his duties.

The old keyboard, at an early period, gave way to a dial transmitter still in use in several cities. In this apparatus there is a separate dial and index for every digit in the number to be transmitted. On receiving a signal from a box, the operator moves the indexes to the respective figures and starts the clockwork into action.

Another method, and one still in use in New York city, is to have a duplicate break-wheel for every signal-box number in the system. The operator, on receiving a signal of fire, selects the corresponding wheel and inserts it on the wheel shaft of the transmitter.

In one of the most improved modern transmitters the dials are all placed on the same shaft, the first dial on the shaft is stationary, and has engraved upon it the figures from one to nine, in as many series as there are movable dials, the other dials simply have apertures which in operation are turned so as to expose the numbers to be transmitted. This apparatus is manipulated with great rapidity, and as only the numbers to which the apparatus is set are exposed to view, the liability to error on the part of the operator is reduced to a minimum.

The testing clock of the original Boston central office has been succeeded by an automatic testing apparatus of excellent design and beautiful workmanship, which indicates and makes a record of the condition of the circuits at stated periods of time.

The best practice demands that there should be two separate circuits to communicate alarms from the central office to the engine houses so that in case of trouble on one circuit, the alarm may be received on the other.

In central offices equipped with new apparatus within the last few years every safeguard is provided to prevent mistakes in the transmission of alarms. With the first blow on the gong from a box signal, a cylindrical indicator revolves and exposes the number of the circuit from which the signal is being received, as well as the number of every box on that circuit. The operator may therefore while counting the signal, set the transmitter, and with one glance at the printed record of the register, and another at the circuit indicator, verify its correctness and have the alarm in process of transmission within five seconds after the completion of the first round from the box.

Discussion.

The President:—This paper is an interesting example of one of the important functions which this body should perform, and that is the putting on record, in complete and permanent form, of the development of various branches of our profession. This particular subject is interesting as being one of the early successful applications of electricity, and also one with which Prof. Farmer's name is associated. I know in my own work that it is often a matter not only of great convenience, but almost of necessity to have various subjects on record and in form sufficiently complete to be worth looking up, and particularly to have them in our own Transactions. There is no place where they can be more available for reference than there. I think that the paper therefore is to be specially commended as putting this subject on record. If there are any questions or discussion upon it they are in order.

Dr. Geo. F. Barker:—I do not remember the precise date at which the magneto was introduced for fire alarm purposes, but I recollect very distinctly seeing the magneto which was driven by water power, and which was used in the fire alarm telegraph in Boston. The fact impressed itself very distinctly on my mind by a little episode I witnessed in the office one day. One of the operators was exhibiting the instrument to some of his friends. There were ladies in the party. He was running the machine very slowly and amusing the ladies by inducing them to take hold of the electrodes, and get a pretty decided shock. Meanwhile there was some construction going on above, and a bricklayer was carrying mortar and stuff from the top on a hod down to the foot of the stairs. He thought he would like to try it, and after the experiments were shown to the ladies, the operator put the whole force of the water on and drove the magneto up to its full capacity. In the meanwhile the hod carrier had been up with his hod and with another load of material he came down, and seeing that the instrument was entirely unoccupied he seized hold of the electrodes with both hands with very great vigor. The consequence was that the bricklayer, hod and all went on the ground. I am sure that that man if he were present could give us the precise date at which the magneto was introduced.

Miss Farmer:—May I tell you just a little incident I have heard my father relate with a great deal of pleasure. At the time of the exhibition of the car he had some other experiments. Among them he put a five dollar gold piece in a basin of water that was charged, which he offered to any man who would take it out. A big brawny fellow came there and took it out quickly, and father found that one of the wires was not connected up. The man had the five dollar gold piece. Father asked him to put it back again and told him he would put another one with it if he would. The man refused. He held on to his five dollar gold piece. There was some excitement and one after another offered to put more to it until I think they got up somewhere in the vicinity of $40 which they offered the man. He said no, that it cost him more than a month's work, and he kept his five dollar gold piece.

The President:—If there are no further remarks on this subject, we will pass on to the next paper on the programme "Electric Traction, Notes on the Application of Electric Motive Power to Railway Service, with illustrations from the Practice of the Metropolitan Elevated Road of Chicago," by M. H. Gerry, Jr., of Chicago. In the absence of the author, the paper will be read by the Secretary.

A paper presented at the 14th General Meeting of the American Institute of Electrical Engineers, Eliot, Me., July 27th, 1897; President Crocker in the Chair.

ELECTRIC TRACTION.

NOTES ON THE APPLICATION OF ELECTRIC MOTIVE POWER TO RAILWAY SERVICE, WITH ILLUSTRATIONS FROM THE PRACTICE OF THE METROPOLITAN ELEVATED ROAD OF CHICAGO.

BY M. H. GERRY, JR.

In the following paper will be found a brief discussion of some of the more important problems arising in connection with the application of electric motive power to the heavier classes of railway service. A number of tests and diagrams from the Metropolitan Elevated Railroad of Chicago, are introduced by way of illustration.

A part of this paper relates especially to the application of electric power to passenger rapid transit on elevated and suburban roads. The conditions for this service differ somewhat from common railway practice. Regular stops are made at frequent intervals; the distance between stations on elevated roads, for example, averaging about 2000 feet. The interval between trains is small, and the time of stops very short. The traffic is irregular, is heavy at certain hours, and is apt to increase and decrease at a rapid rate. To make the fast running time desired, the speed must increase up to the point where the brakes are applied; thus the maximum of speed is high compared with the mean speed. There is little or no opportunity for maintaining the speed, and the running time depends almost entirely upon the rate of accelerating and retarding of the train.

With a given number of stops per mile, the amount of power required will increase very rapidly with the speed beyond a certain point, and the cost per car mile will not furnish a reliable basis of comparison for the motive power of different roads unless the conditions are the same. A slight difference in the average speed, or in distance between stations may cause a considerable change in the amount of power required.

There are in operation at the present time several noteworthy examples of the application of electric motive power to the heavier classes of railway service. The most important of these installations are the Lake Street and the Metropolitan Elevated roads of Chicago, the Baltimore Tunnel Line of the Baltimore and Ohio, and the Nantasket and Berlin lines of the New York, New Haven and Hartford Railroad. From the experience gained on these roads, there is no longer a question in regard to the ability of properly designed electric motors to operate trains of the heaviest weights in service, and at any speed permissible under practical railroad conditions. In the future, matters of efficiency and general utility must determine the desirability of electric power for any particular railway service.

Certain operating conditions have a special bearing on the efficiency of this form of motive power; the most important being the frequency of the train service. If traffic is such that a large number of trains must be operated on a division, the electric power will have an advantage in point of economy, over steam locomotives; and if the trains are few, the reverse will be the case. This condition holds good independently of the weight of the trains or of the speed attained. The length of the line is in itself no bar to the successful operation of an electric railway system, as, by using alternating current apparatus, the power stations may be located favorably, and at long distances apart.

The distribution of the current to the trains, while it presents many practical difficulties in detail, is not so serious a problem as it was thought to be at one time. Of the three systems of over-head conductor, conduit, and third rail, the last has given the best results, and is advisable wherever the conditions are such that it can be installed. For roads operating on their own right of way, there is really no serious objection to the third rail, and all of the difficulties encountered at crossings, switches and in yards can be overcome by methods already in use on the roads named above, or by other devices that have been proposed. It is not to be expected that all details of such a system are in an entirely satisfactory and final form, but they are practically operative at present and being constantly improved as difficulties develop in service. The experience already gained also justifies the statement that a reliable overhead or conduit system for heavy service can be constructed if the conditions favor the use of such methods.

THE METROPOLITAN ELEVATED RAILROAD.

This system, now in its second year of operation, is the largest road in existence employing exclusively electric power for a heavy passenger service.

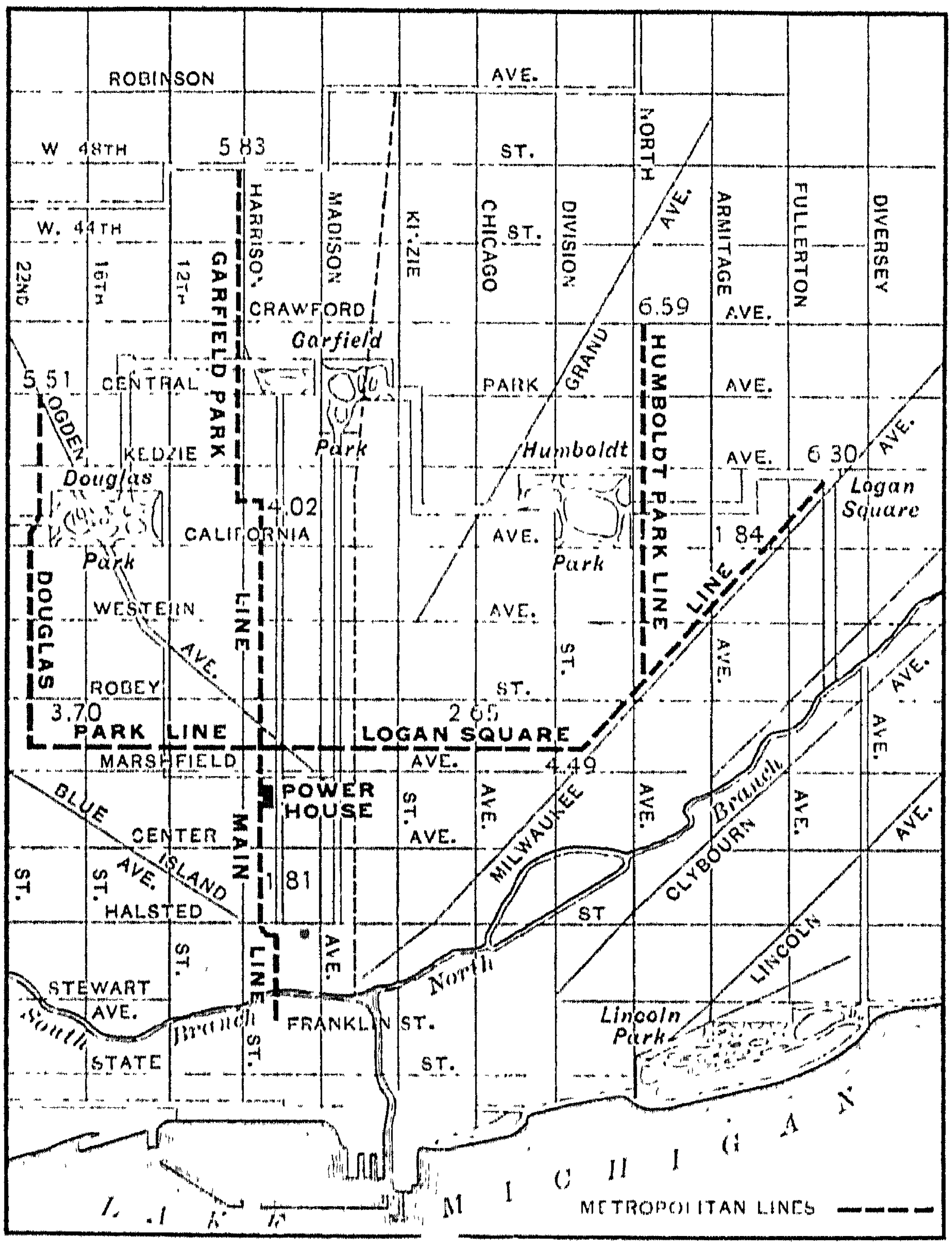


FIG. 1.

The structure has four tracks, from Market street west to Marshfield avenue, at which point three double track lines diverge. The northerly branch divides again near Robey street into two double track branches. From Market street to each of the terminals, the distance is about six miles. (See map, Fig. 1).

Current is conveyed to the trains by the third rail system; the "trolley rail" being placed 20½ inches outside, and 6¼ inches above the running rail. It is of the common "T" section, bonded with leaf copper bonds, and divided into sections to provide for expansion. The insulation for the third-rail, on all but a small section of the road, consists of hard-wood blocks, mounted on small iron chairs fastened to the ties. On a recent extension an improved form of insulation made of stone-ware has been tried with success. The electric leakage is small at all times. In dry weather it is entirely negligible and in wet weather is never more than a few amperes. It is greatest after a dry season, when the first shower is washing the accumulated iron dust from the insulating blocks. Steel rails are used for feeders, and copper only to make connections. The feeder system is divided into six sections, which are tied together at junction points through circuit breakers placed in the interlocking towers.

The rolling stock consists of motor cars, passenger cars and a few coal and flat cars. The motor cars measure 47 feet in length and weigh about 62,000 pounds when loaded to their maximum capacity. They are mounted on rigid bolster locomotive type trucks, having 33-inch steel tired wheels. The truck centers are 33 feet 6 inches apart and the truck wheel base 5 feet 6 inches. One truck of each motor car is equipped with two motors, each nominally rated at 2,000 pounds drawbar pull. The motors are operated by series parallel controllers, situated in the cabs at each end of the car. Rheostats of the packed ribbon type, used in connection with the controllers, are placed underneath the car. A circuit breaker placed in each cab is used both as a safety device and as a main switch for opening the circuit between the trolley device and the controller. A main fuse box is also provided, and placed in one of the cabs as an additional safety device, but experience has shown that failures of the circuit breaker to act are so rare, that the former piece of apparatus might well be omitted. Circuit breakers have proven very satisfactory for this service, as they cost little for maintenance, are reliable as safety devices, and by their quick action reduce to a minimum the damage to apparatus from grounding and short-circuiting.

The cars are warmed by electric heaters arranged in three circuits, two of which take about seven amperes each and the remaining circuit about four amperes. All of the heaters are required only in the coldest weather, and are turned on and off by the trainmen. By cutting out all or part of the heaters for a short time when the traffic is heaviest, the peak of the load can be reduced and the heaters used to improve the load factor.

The air-brakes are of the direct or "straight" air type with an additional re-enforce cylinder. The air is compressed to 60 pounds by a vertical pump, driven by a motor of about three horse power. The pump motors have automatic control, regulated by the air pressure and also hand control from each end of car. The pump with its motor and automatic controller is placed in one of the cabs.

The passenger cars are 47 feet in length and of the standard pattern, in use on all elevated roads. They are mounted on swinging bolster trucks, having 30-inch wheels and when loaded to maximum capacity weigh about 46,000 pounds. Two, three, and four car trains are in service at different hours, corresponding with the traffic. About 1,200 trains are handled daily and under very close headway out of Franklin street terminal.

The power house is supplied with water tube boilers, mechanical chain stokers, coal and ash handling machinery, forced draft, automatic oiling system and all modern appliances. The boilers are 14 in number and work at 165 pounds pressure. There are four vertical cross-compound engines, direct connected to the electric generators. The condensing water is taken from the Chicago river by tunnel, and water for the boilers from the city mains. There are four electric generators, two of 1,500 kilowatt and two of 800 kilowatt capacity. The switchboard is placed on a gallery and is provided with the usual instruments, including recording wattmeters for each generator. There are six feeder panels corresponding to the divisions of the feeder system.

THE POWER ABSORBED BY TRAINS.

In an electric railway system, the mechanical energy supplied at the engine shaft may be divided, for purposes of discussion, into two general classes. First, that finally absorbed or utilized in propelling the train, and, secondly, the energy lost in transformation and transmission, including losses in generators, line, rheostats, and motors.

The first division or class, that is, the energy to propel a railway train, may be divided again into three parts: First, that required to overcome inertia and accelerate the train to its maximum speed after each stop. Secondly, the energy required on account of ascending grades. Thirdly, that required to overcome train resistance; including friction, air resistance, etc. If the stations are far apart, the energy required to accelerate the train may be neglected without serious error, but for a service where trains make frequent stops, and the maximum speed is high, compared with the mean speed, it becomes of importance, and may easily be the greatest of all losses. The amount of energy required for train acceleration, obviously depends upon the number of stops, the train weight and the maximum speed. Knowing these quantities, it can be readily determined from the common mechanical formula for kinetic energy. $U = \frac{w v^2}{64.4}$

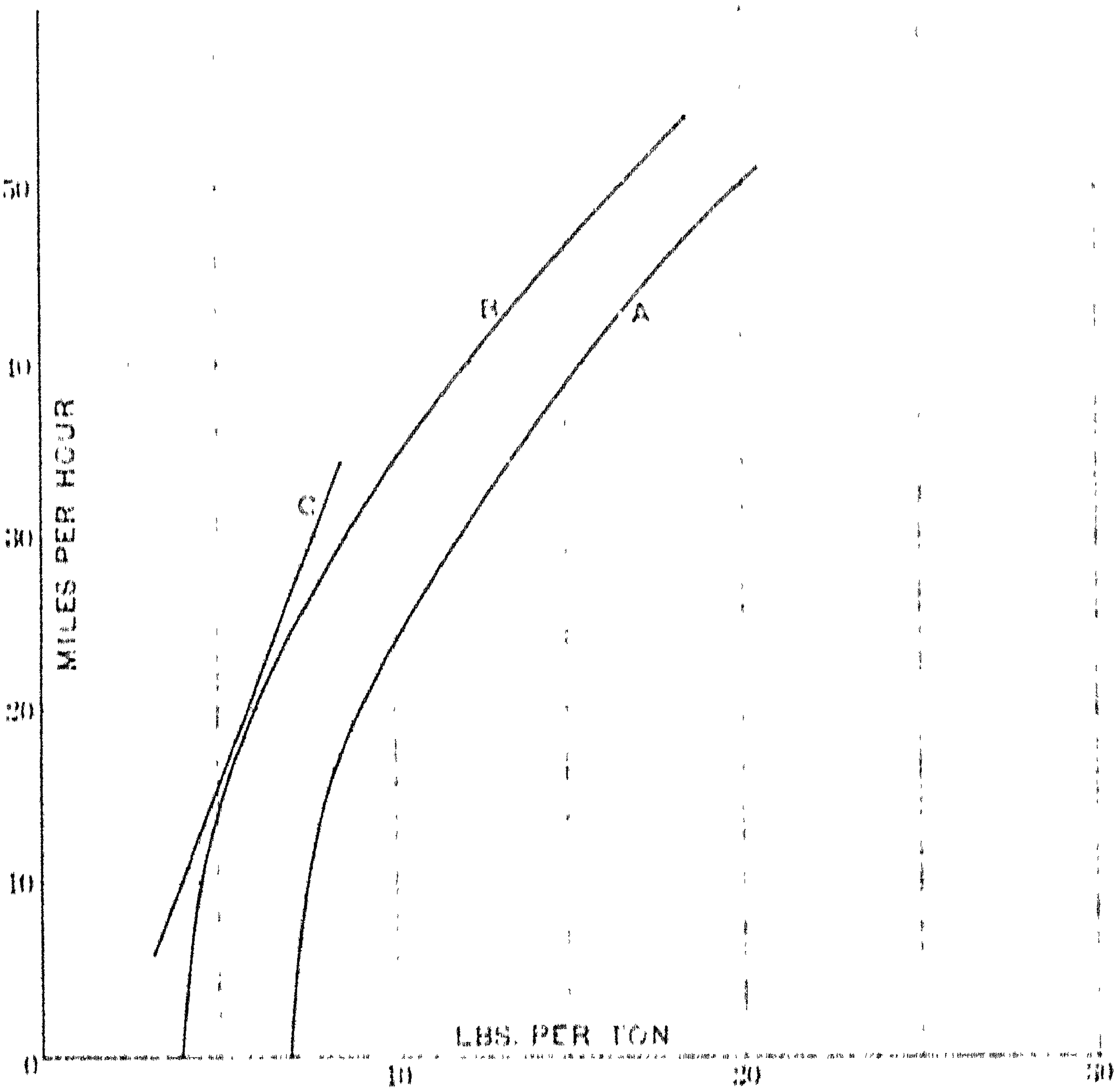


FIG. 2.

The horizontal effort or drawbar pull required to produce a certain acceleration in a given time may be obtained from the mechanical formula. $f = \frac{w v}{32.2\,t}$.

The work done in ascending grades is the product of the train weight and the vertical distance the train is lifted. The horizontal effort required to take a train up a grade is equal to the product of the train weight by the per cent. of grade.

Train resistance, as used in this paper, includes all retarding forces other than those due to inertia and grades. Formulas for determining this quantity are empirical and are based upon experimental results, where the conditions have varied widely. D. K. Clark, in "Railway Machinery," recommends a formula

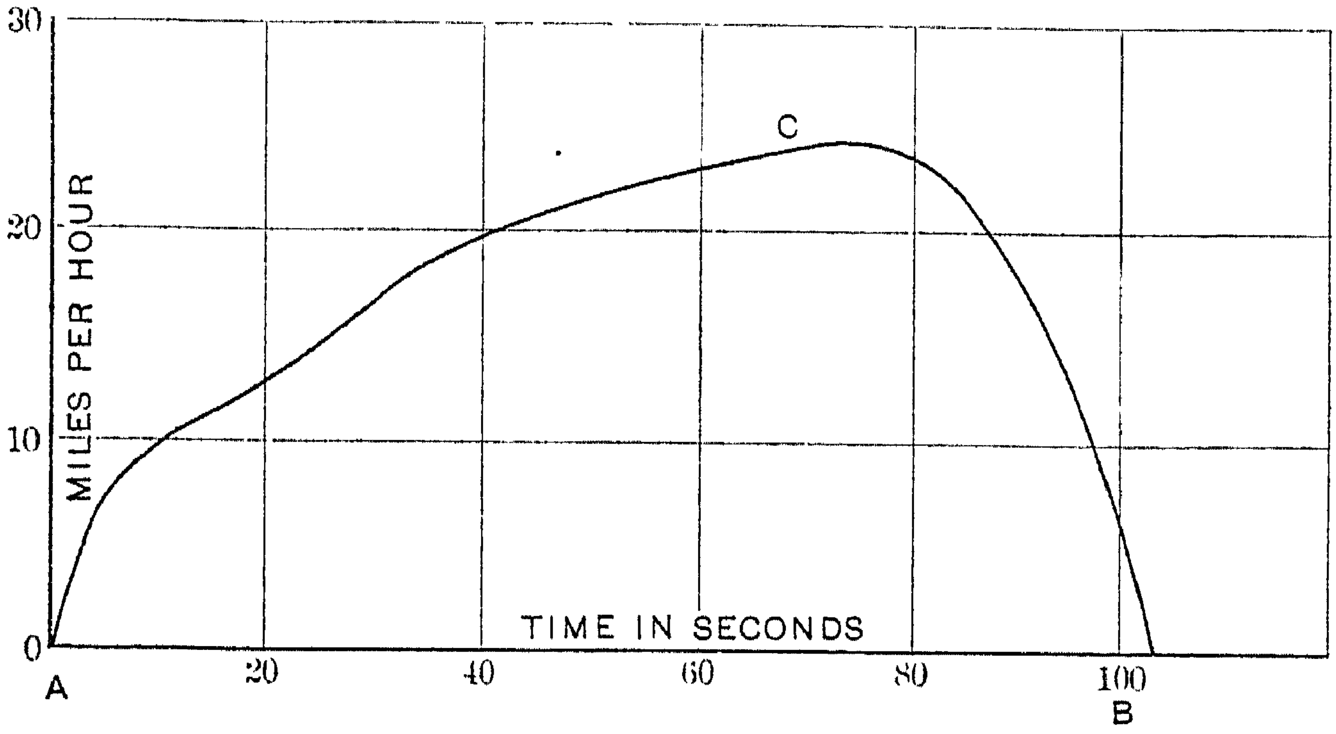


FIG. 3.

which, reduced to tons, of two thousand pounds, becomes $R = 7.1 + \frac{v^2}{192}$. Another formula in use is $R = 4 + \frac{v^2}{200}$, where R = resistance in pounds per ton of train weight, v = speed in miles per hour. These two formulas have been plotted in Fig. 2, and are marked respectively A and B. From measurements taken on the Metropolitan Elevated, the curve C has been determined and is used in the following discussions.

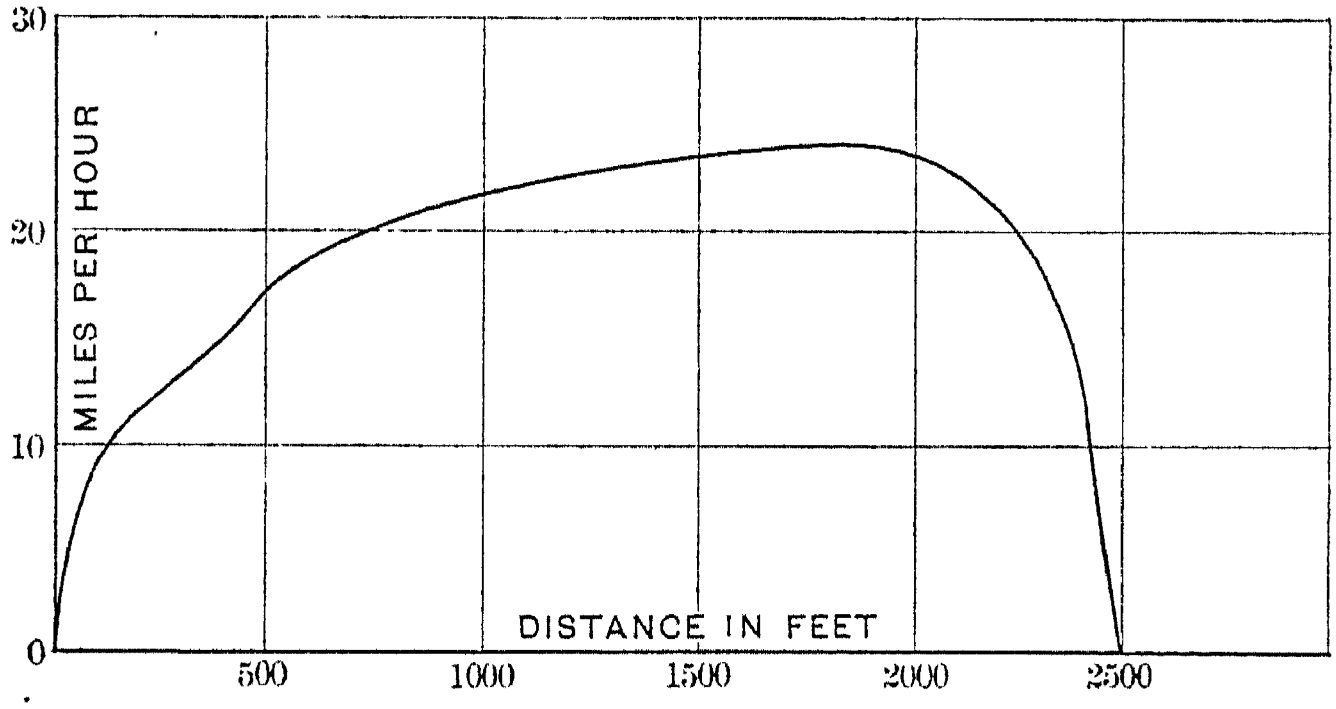


FIG. 4.

In Figs. 3 and 4, are shown actual speed curves on a time and a distance base, for a train running between stations, 2,500 feet apart. For the purposes of discussion, consider the train weight as 100 tons and in the first case assume it to be on an ascending grade of ½ of 1 per cent. From the curves, the speed at the time brakes are applied is 24 miles per hour, and the kinetic energy at that speed, for the train, is 3,800,000 foot pounds. The time consumed up to the point where brakes are applied is 77 seconds, and the energy to overcome the 0.5 per cent. grade while the train is passing over the first 1,900 feet, is equal to 1,900,000 foot pounds. The energy to overcome train resistance for the same distance, is equal to 1,045,000 foot pounds. Summed up, the energy would be as follows:

For accelerating the train	3,800,000	foot pounds.
For the grade	1,900,000	" "
For train resistance	1,045,000	" "
Total energy required	6,745,000	" "

This represents the total energy that must be supplied to the train from the time of starting, up to the moment the brakes are applied. From this point, the acceleration is negative, and the kinetic energy of the train is absorbed by train resistance, the grade and the brakes. The amount taken up by the brakes is 2,900,000 foot pounds.

The above case is for the train on a 0.5 per cent. ascending grade. For the train on a level the figures would be as follows:

For accelerating train	3,800,000	foot pounds.
For train resistance	1,045,000	" "
Total energy required	4,845,000	" "

The amount absorbed by the brakes in this case will be 3,500,000 foot pounds.

For the same train and speed conditions for a 0.5 per cent. descending grade, the figures are,

For accelerating the train	3,800,000	foot pounds.
For train resistance	1,045,000	" "
Total energy required	4,845,000	" "
Supplied by descending grade	1,900,000	" "
Total external energy required	2,945,000	" "

The total energy absorbed by the brakes in stopping the train in this case is equal to 4,100,000 pounds.

The foot pounds per ton mile in each of the cases cited are as follows:

On an ascending grade	142,000	foot pounds.
On a level	102,000	" "
On descending grade	62,000	" "

The average speed taken from the curves in the cases cited is 16.5 miles per hour, not including stops. Allowing twelve seconds for a stop, it is fifteen miles per hour.

The average rate of using energy or the power, allowing time for stops, is as follows:

On a .5 per cent. ascending grade	106.5 H. P.
On a level	76.5 "
On a .5 per cent. descending grade	46.5 "

The power may also be divided as follows:

For accelerating the train	60 H. P.
For ascending grade	30 "
For train resistance	16.5 "

These figures do not, of course, include losses in applying the power, and only represent the energy which must be applied at the rails to produce the results in the special cases named above. The conditions vary widely at times on the same road, but the above examples may serve to show how great is the percentage of power required to accelerate the trains when the stops are frequent.

In a speed curve with a time base, such as Fig. 3, the area enclosed is proportional to the distance travelled. That part of the area enclosed by the curve from B to C, a perpendicular from the point C, and the base line, depends on the form of the braking curve and hence on the efficiency of the brakes. The area enclosed by the curve from A to C, the perpendicular and the base line, depends on the form of the accelerating curve. The distance between stations being fixed, the area enclosed must be constant and independent of the form of the curves. The shape of the curve may be altered, however, in two general ways, first, by changing its form so as to still enclose the same area, with the same length of base, and secondly, by altering the form of the curve and changing the length of the base. This latter change will alter the time between stations, while either of the changes may or may not affect the amount of power used, this depending principally on the maximum speed attained. In Fig. 5, the curves A and B represent equal distances passed over in equal times, but the energy required for curve A is materially less than for curve B. The amount of power required in any case will depend largely upon the form of the speed curve, that is, upon the rates of accelerating and retarding of the train, and it is always desirable to keep the maximum speed as low as possible. Motors efficient at high speed are sometimes wasteful of energy because of insufficient torque, at starting and at low speeds, to produce a good form of acceleration curve.

The train weight may be considered as made up of two parts, the live, or paying load, and the dead load, which includes the weight of rolling stock, motors, etc. As the amount of power required by the train varies almost directly as the weight, it is desirable to have the non-paying or dead load as small as possible. In order that there may be sufficient traction, a separate locomotive must weigh between four and five times the maximum drawbar pull required by the train, all of which is dead load, in addition to that of the cars. It has been stated that a rapid acceleration is desirable if there are many stops, but as each pound of increased maximum drawbar pull from a locomotive must add four or five pounds to the dead weight of the train, a point is soon reached where no further advantage is obtained by increasing weight on the drivers and drawbar pull. The weight admissible on the locomotive driving wheels, on account of track and structure, also limits the amount of traction, hence the drawbar pull and rate of train acceleration. Thus, for a service combining high speed and many stops, there are advantages in a form of motor which may be so placed as to utilize a part of the car weight and live load, for purposes of traction. The cars should weigh as little as possible so as to reduce the total dead weight of the train, for it is well known that the ton-miles of paying load form only a small percentage of the total ton-miles moved. On elevated roads it is probably below six per cent. on the average and on some roads, below one per cent.

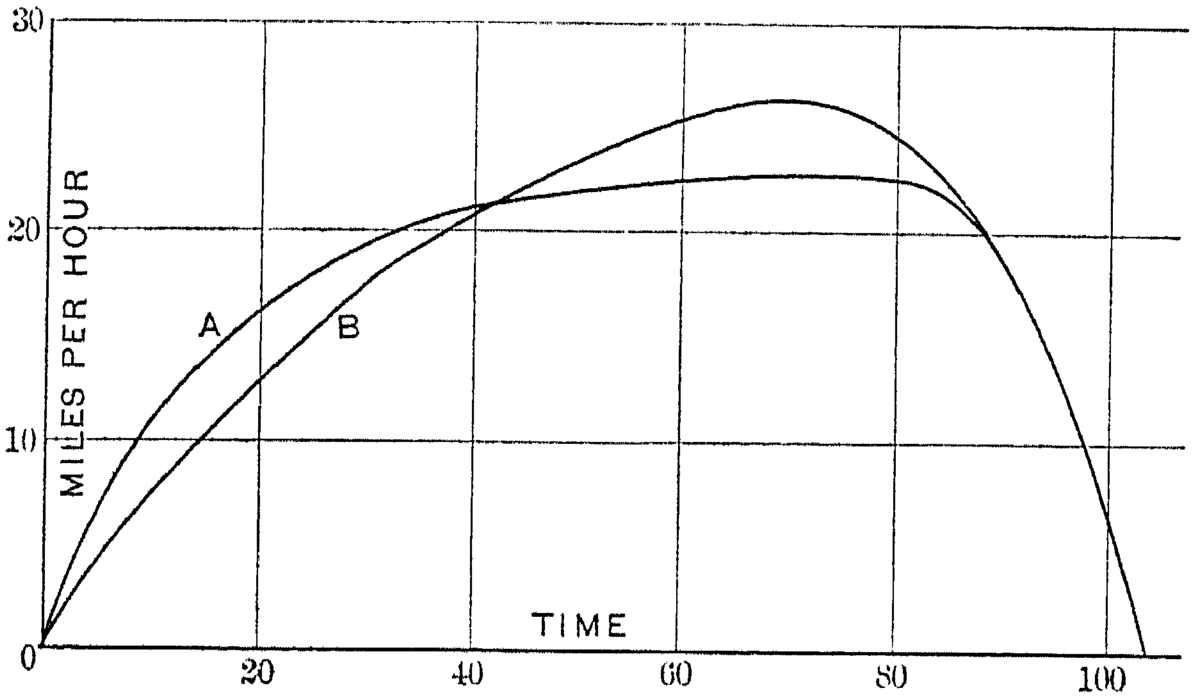


FIG. 5.

It is hoped that these remarks may direct attention to the question of economy in the use of power or to what may be called train efficiency, in contradistinction from the efficiency of the apparatus used in the generation and transmission of the power to the car axles. This latter subject will now be considered.

The Motors and Controlling Apparatus.

At the present time, direct current series motors with series-parallel controllers are in all but universal use for electric railways. Shunt motors are in service in Europe to a limited extent, and alternating current motors have been given a trial. The latter have advantages under certain conditions for lines of considerable length where there are but few stops. Alternating current motors tend to run at a nearly constant speed, approaching synchronism, and do not regulate with the same facility and efficiency as direct current motors. They develop, however, a good starting torque and may even produce a better form of torque-speed curve than the common series motors. The double conductor required with alternating current motors is an objection, but there are many advantages in their favor; the system is untried and its possibilities are not fully known.

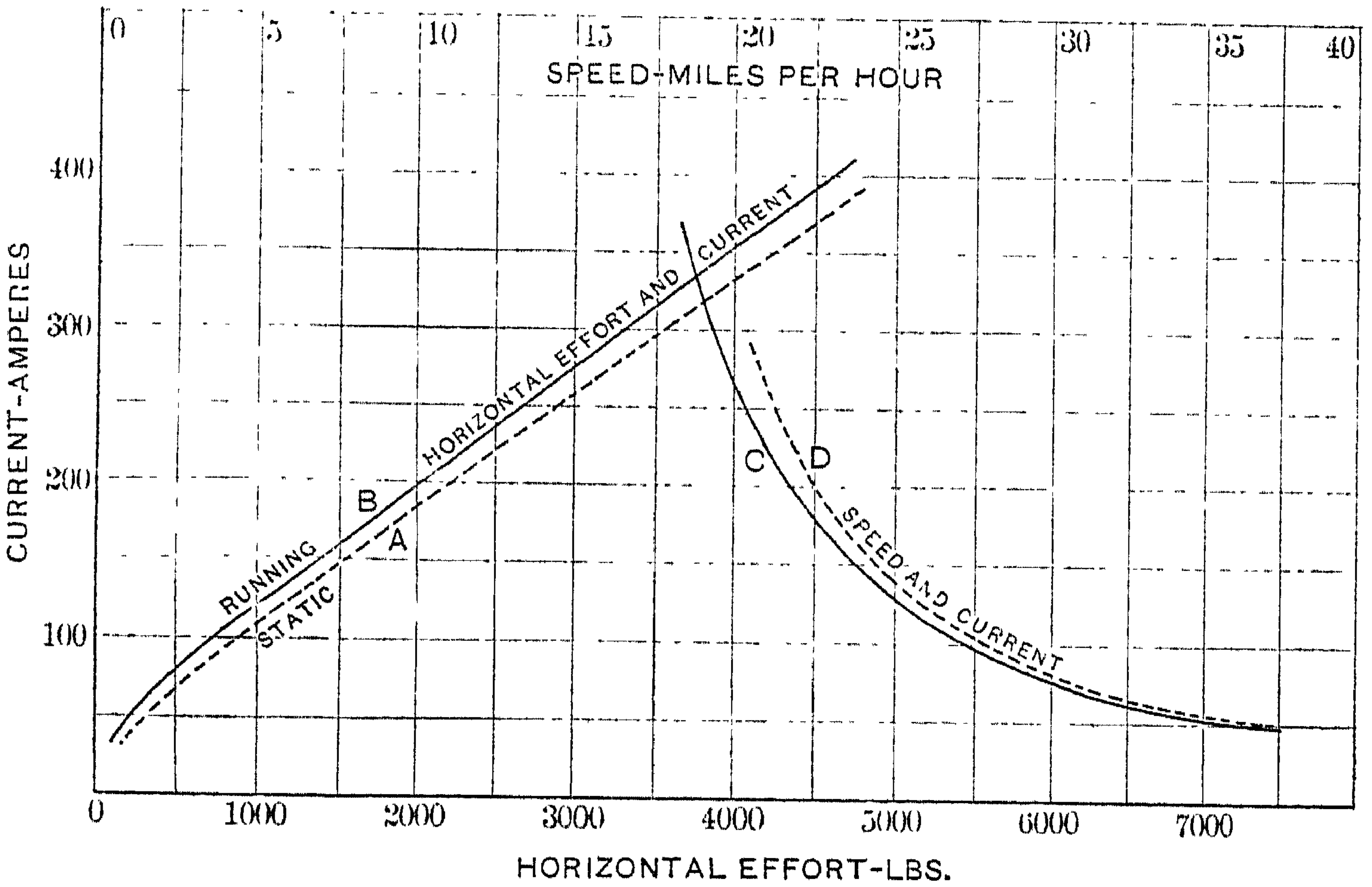


Fig. 6.—Speed and Horizontal Effort at 500 Volts.

The characteristics of the motors in use on the Metropolitan Elevated are introduced in this paper rather than a general discussion, and it is hoped that this will be acceptable. By modifying the design the relations existing between the torque, speed, current and voltage, may be varied within wide limits, but the general relations are always the same and are well illustrated by the diagrams below. All modern railway motors are much alike, the designers having been forced by the conditions imposed upon them, into practically one general type of machine. The requirements are a large output, ability to withstand heavy overloads, freedom from sparking, a low rotative speed, light weight and limited space. The result is the cast-steel multipolar motor, operating with nearly saturated fields and high magnetic densities in the armature.

In electric motors, the relations between speed, horizontal effort (or torque), current, voltage, and efficiency are all fixed, and may be readily determined for any particular motor. For most practical purposes it is best to represent these relations graphically. At A, in Fig. 6, the relation between current flowing and the static horizontal effort produced, is shown for the standard motors in use on the Metropolitan Elevated Road. Curve B, in the same figure, represents the horizontal effort produced when the motor is running with 500 volts at the terminals and at the speeds shown by C. The horizontal distance between A and B, represents the loss in horizontal effort due to friction and core losses. Curve D, in the same figure, gives the speeds which the motor would attain under the conditions named if there were no internal resistance, and the horizontal distance between the latter curve and C, represents the loss in speed due to such resistance. Thus the losses in a series motor may be divided

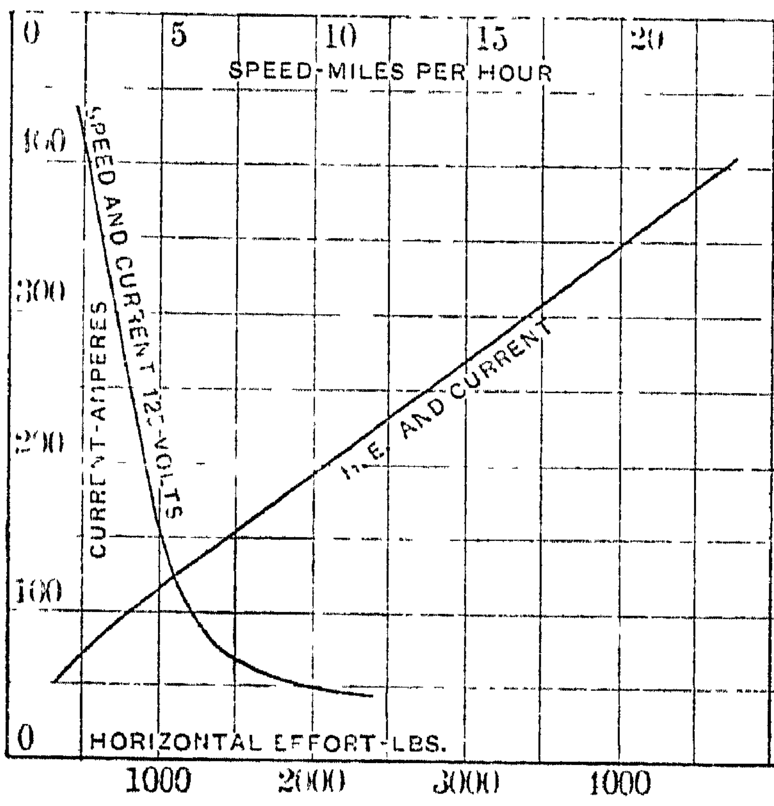


FIG. 8.—Speed and Horizontal Effort at 125 Volts.

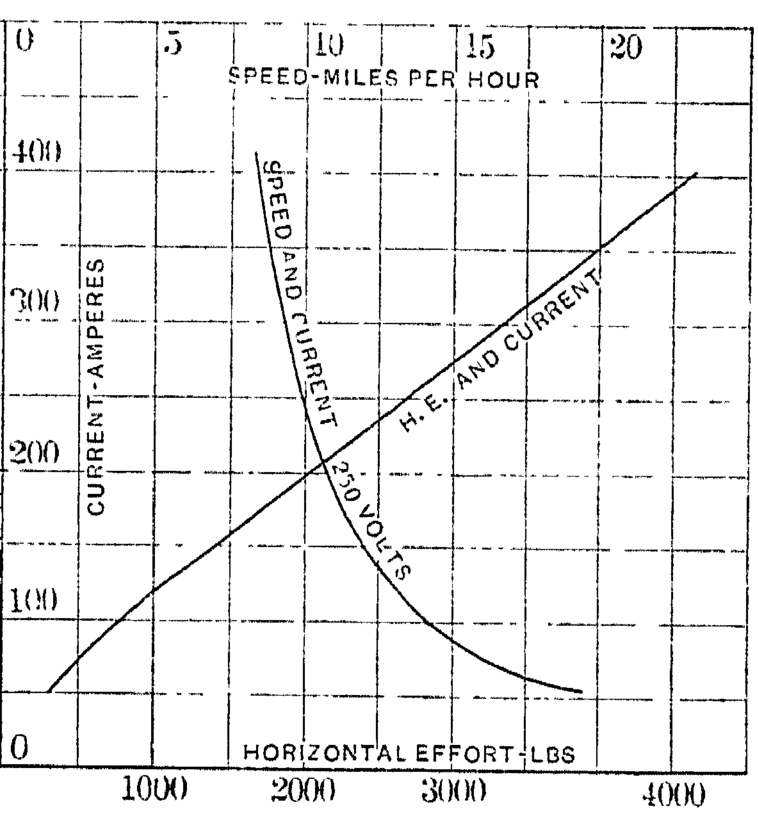


FIG. 7.—Speed and Horizontal Effort at 250 Volts.

into two classes, those that lessen the torque and those that reduce the speed. In Figs. 7 and 8, the relations between current, speed, and horizontal effort are plotted for the same motor at 250 and 125 volts. The static horizontal effort is the same in all cases, but the running horizontal effort is slightly greater for the same current at the lower voltages, because the losses which affect it are less at the lower speed. At the same time the percentage of loss due to internal resistance becomes greater, as it depends upon the current flowing, while the total input of energy varies with the electrical pressure as well; hence, the reduced efficiency at the lower voltages. Curves of efficiency, in relation to the current, are plotted in Fig. 9, for the same voltages. In Fig. 10, the efficiency is plotted to the speed, and it will be seen that the curves fall off rapidly above or below a certain narrow range of speed over which the efficiency is high, at any one voltage. There is a considerable range of current and horizontal effort, over which the efficiency is high, as can be seen from Fig. 9, but it corresponds to only a small speed variation. The relations of speed to horizontal effort are given in Fig. 11. The maximum working range of the motor is from 350 to 4,000 pounds horizontal effort, and the total speed variation on this range at 500 volts will be about 14 miles, and at 250 volts, about 10 miles. The range of speed obtained in service at any one voltage is practically about one-half this amount, and if 250 and 500 volts be considered as the pressures

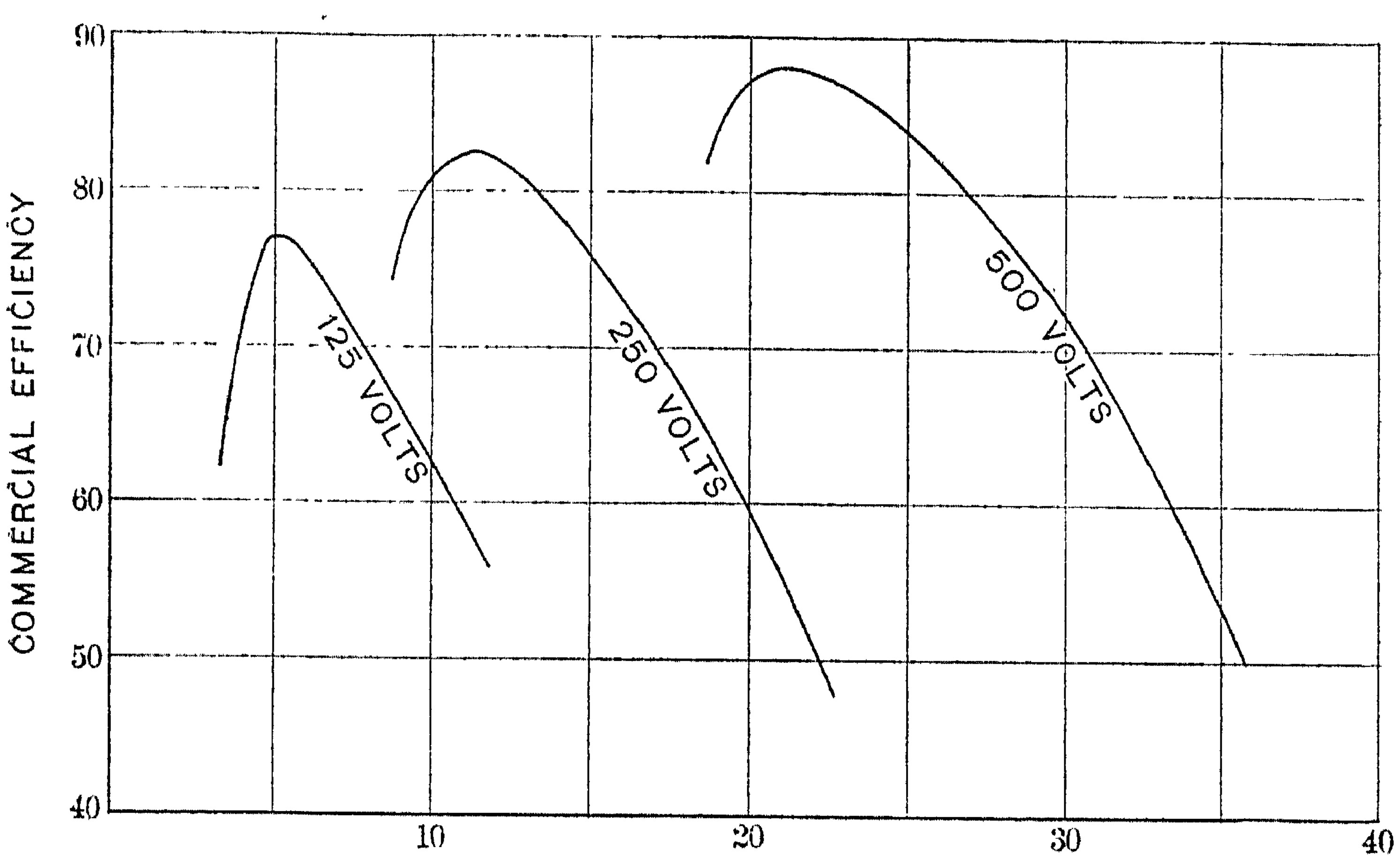


FIG. 9.

at the motor, in series and parallel combination, then the total range of speed, without further alteration of the voltage by resistance in circuit, will be about 12 miles over a total speed range of 34 miles. For each combination of motors in series parallel, there is a certain range of speed over which the efficiency is equal to that of the motors; but at all other speeds, resistance must be introduced in circuit and the efficiency is reduced.

The weight of the armature and other revolving parts is a feature of importance in motors designed for a high-speed service, requiring frequent stops. These parts should be as light, and the rotative speed as low as possible. The armatures of the Metropolitan motors weigh approximately 1,400 pounds and are $18\frac{1}{2}$ inches in diameter. At 800 revolutions per minute, corresponding to 25 miles per hour, the kinetic energy in each armature is equal to 43,000 foot pounds. Thus, for a two motor equipment, 86,000 foot pounds of energy are dissipated each time the car is stopped from a speed of 25 miles per hour. This amount of energy will vary with the square of the maximum speed and if stops are frequent, it becomes an appreciable loss.

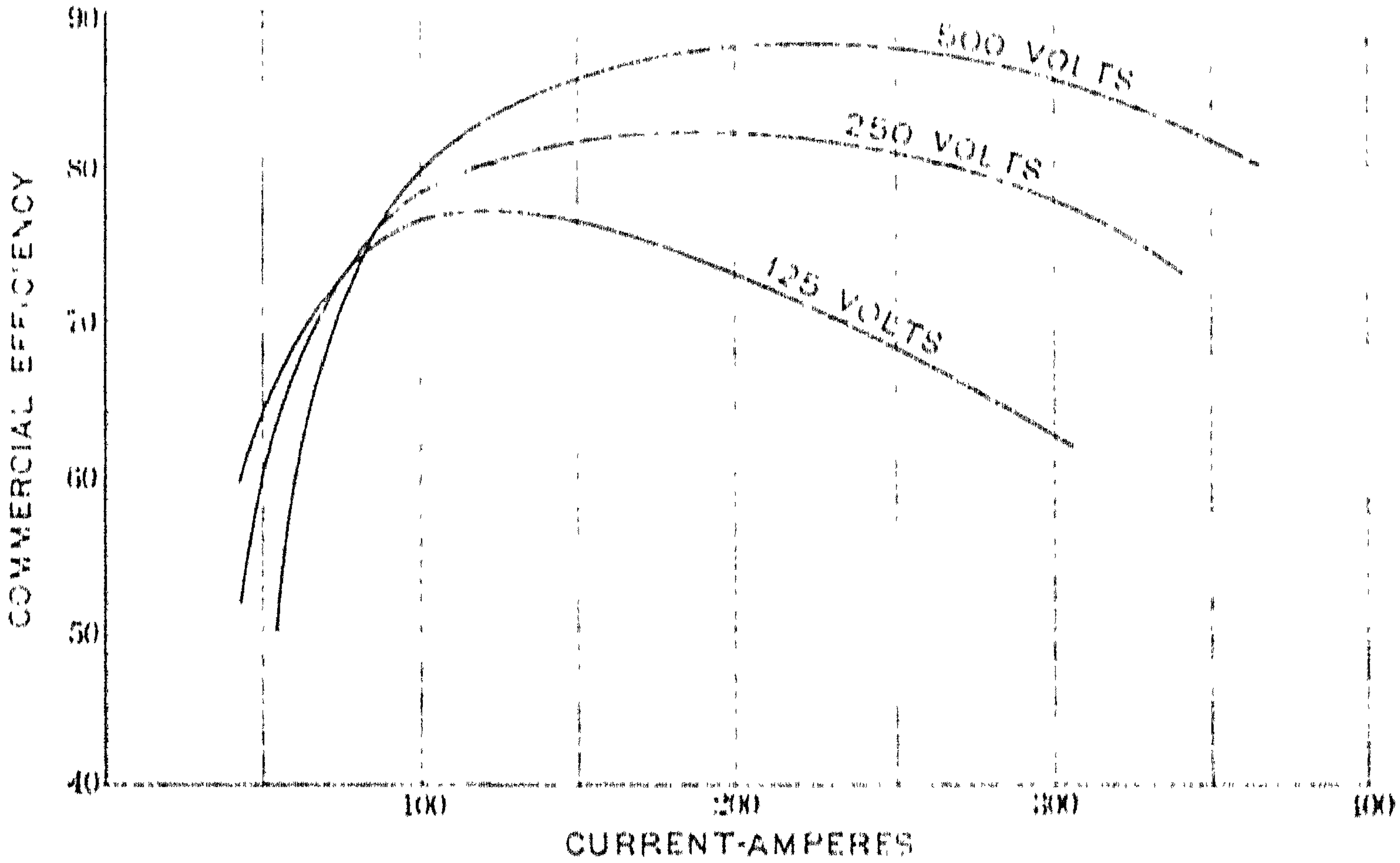


Fig. 10.

The average load a motor is capable of sustaining is fixed by the permissible increase in temperature. The amount of such increase will depend on the average load, the efficiency of the motor and the extent and character of the heat radiating surfaces.

The actual load on a railway motor differs at times, very widely, from the average load, and ability to withstand these fluctuations, will depend in part on the heat storage capacity of the motor. The metal acts, to a considerable extent as a reserve of heat, receiving it when the motor is doing its heaviest work and giving it up at lighter loads. A glance at the load diagrams in the latter part of this paper will serve to show how great these fluctuations may be under certain conditions. The amount of heat radiated in a given time varies greatly with the speed of the car and the temperatures. With the air at 60° F., and under average working conditions, a Metropolitan motor will radiate heat at the rate of about 650 British heat units per minute. This is equal to 15 horse-power, corresponding about to 60 horse-power of loading. But these motors will readily withstand for a considerable period of time a loading of three times this amount. Most of the heat produced by this additional loading must be stored in the metal of the armature and frame. A considerable part of the

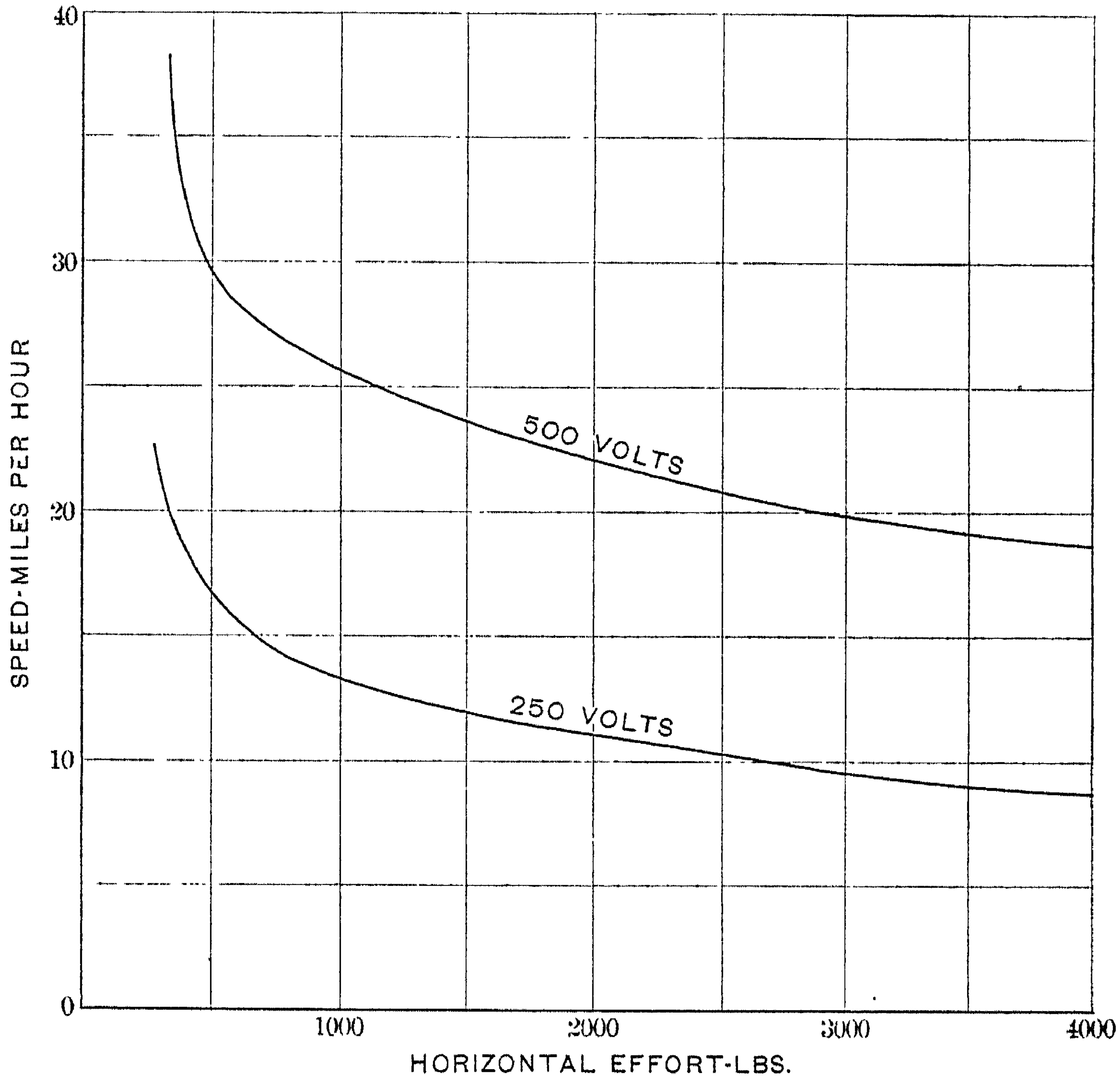


FIG. 11.

heat is generated in the armature, but its thermal capacity being nearly 150 heat units per degree, a large amount of heat energy can be stored before the temperature reaches the danger point. Slow speed armatures in general have more metal in them, and are thus better able to stand a variable load.

The speed of a series railway motor at any given impressed E. M. F. is fixed by the total resistance of the train. The horizontal effort developed must just equal the resistance, or the velocity will change; therefore, if it be desired to maintain a constant speed, or to vary the velocity in any manner not corresponding to the fixed relations of speed and torque for the particular motor and voltage, it will be necessary to alter the impressed E. M. F., or to commutate the fields. To obtain this variable E. M. F. at the motor terminals from the constant E. M. F. of the line, many arrangements have been proposed, but only two are in use to any extent. They are by rheostat in the main circuit, and by grouping two or more motors in series and parallel combinations. Practically the two methods are combined, and are now in nearly general use. The rheostatic method wastes the energy represented by the reduction in voltage, and the series-parallel arrangement provides two or more voltages at the motors without preliminary loss. The controllers in use on the Metropolitan are two combination series-parallel and have three steps on the rheostat for each voltage. The losses in this apparatus vary from 10 to 20 per cent., depending upon the skill with which it is handled. With care this can be kept down to 10 per cent., making no allowance for the reduced efficiency of the motors at the lower voltages. The series-parallel system has decided advantages over all other methods thus far tried in practice, but it lacks flexibility and ultimately may not prove to be the best for heavy railway work and especially for high speed service.

The selection of the proper motors and controlling apparatus for a given service, deserves more attention than it has generally received. The horse-power and maximum speed have too often been the determining quantities. A rating based on horse-power is now understood to be of little value, and the maximum speed of which a motor is capable may be of still less account as representing its performance with a train. Quite generally, motors have been speeded too high, the result being insufficient starting torque, a poor commercial efficiency and less average speed than a better selected motor would have developed.

THE GENERATORS AND FEEDERS.

Anything like a complete discussion of modern railway generators or of the problems connected with railway feeders, might well be the subject of a separate paper. It is designed here simply to touch upon a few points relating to the general system.

Railway generators at the present time are nearly all of a direct current type, but there is reason to believe that in the future, two and three-phase alternating current machines will be installed. The development of the rotary transformer will be largely responsible for this change in practice. Power stations can be more favorably located in respect to fuel and water supply, and through sub-stations furnish power to larger areas. With this change will come also greater economy in the production of power, which cannot but have a favorable effect on the development of the electric railway.

The commercial efficiency of railway generators varies from 90 to 95 per cent. Under favorable conditions, the average or "all day" loss for large direct connected machinery (units of over 600 K. W.) is about seven per cent. Direct connected alternating current generators give about the same efficiency as direct current generators. Commercially, the best results are obtained with a few units of large size. It is unnecessary and poor practice to install many small units for railway work.

The load line of an electric railway is subject to two kinds of fluctuations; first, those sudden changes caused by the starting together of a number of trains, and secondly, the more gradual change due to the variation of traffic at different hours of the day. On roads operating but few cars, the fluctuations due to the first cause are of considerable amount, but on large systems with many cars the changes in loading from starting up of trains are very slight—hardly noticeable, in fact—and this is especially the case if the feeders are tied together and form a network. There still exists, however, the change in the load line corresponding with the traffic. A railway load line differs from that of a lighting station in having two nearly equal "peaks" or points of maxima, one in the morning and one in the evening. These variations are best taken care of by cutting in and out units, while the momentary changes can usually be cared for by a slight overloading of the machinery. Engines and generators for railway purposes have a good efficiency over quite a wide range and generally stand overloads very well. In Fig. 12 are shown seven load curves from the power station of the Metropolitan Elevated. The curves correspond to the days of the week and indicate the average power taken, but do not show momentary fluctuations, caused by the movement of trains. The chief characteristics of these curves are the two decided "peaks" ocurring daily with great regularity. The peaks vary as to amount and time, with the season of the year, and to some extent with the weather, but are always present in a marked degree. Street railway systems with many lines extending to different parts of a city, usually show a station load with less decided and broader peaks. This is due in part to the habits and occupations of the patrons of the various lines which determine the hours of maximum traffic. When combined, the load curves from a number of such lines will give a more favorable station load than any one line or group of lines in the same section of a city.

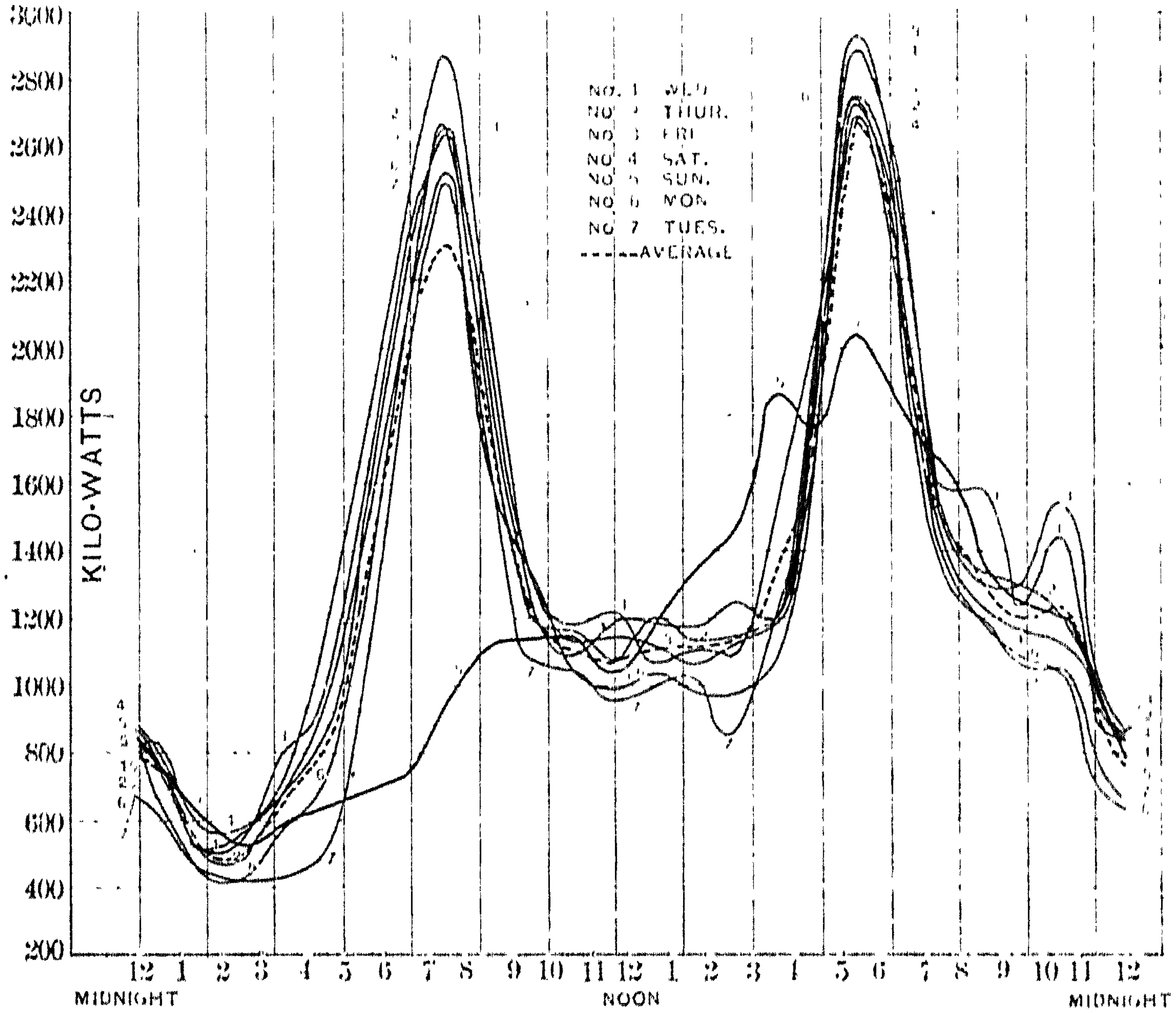


FIG. 12.

The load curves of the Metropolitan have proven to be a very sensitive index of the traffic. A delay on the competing cable lines or increase of travel from any cause is at once noticable in the power house. The greater station loading is due not so much to the increased weight in passengers carried, as to the longer stops necessary to discharge and to take on passengers; thus requiring a higher speed to keep the trains on time.

The feeder system has an effect upon the form of load curves as well as upon the total amount of energy required. The highest percentage of loss will occur at the moment of greatest loading, but this rarely takes place at the same time on different sections, and an advantage is obtained by connecting the lines together to form a net work as far as possible. Feeders are usually divided into sections as a matter of safety and convenience. The best economy of copper and of power, and the most favorable load lines are obtained when the number of such sections are as few as consistent with the safety and flexibility of the system. When feeder sections are connected, the best practice calls for a fuse or circuit breaker in this circuit. The permissible percentage of loss between the power house and the trains, is partly a commercial question, depending on the cost of power, and interest on the feeder investment. Transformers, rotary converters, boosters, batteries, and similar apparatus forming a part of the feeder system, should be considered with special reference to cost, operating expense, all day efficiency and effect on the load factor of the generating station.

THE EFFICIENCY OF TRANSMISSION.

The energy dissipated between the engine and the car axles may be divided into three parts, that lost in the electrical generators, the losses in the transmission lines (including transformers, rotaries, etc.) and the losses in the car controlling apparatus and motors.

The amount of loss in the generators will depend upon their efficiency and average loading. Modern railway generators have good efficiency above half load, and in stations designed with reference to the load line, there is but little difficulty in keeping the machinery above three-quarters at all times. In the table below are given the efficiencies for a number of direct connected machines of modern design.

TYPE OF MACHINE.	COMMERCIAL EFFICIENCY.			
	Full load.	¾ load.	½ load.	¼ load.
D. C. Generator, 700 K. W.	94	93	92	—
D. C. Generator, 750 K. W.	93.5	92.5	91	85
D. C. Generator, 800 K. W	96	95	92	—
D. C. Generator, 1,500 K. W.	94.5	94	93	—
A. C. Generator, 750 K. W.	94	93	91	—
A. C. Generator, 600 K. W.	93.5	92	87	82
A. C. Generator, 700 K. W	94	92	90	83
A. C. Generator, 650 K. W.	93.5	91.5	89.5	—
Rotary transformer, 650 K. W.	94	92	90	—
Rotary transformer, 600 K. W.	95.5	92.5	90	84

With machines of this type and size, the all day efficiency ought to be about 92 per cent. A sub-station provided with rotaries and static transformers working under a good average loading, should have an efficiency of about 89 per cent.; a loss of 8 per cent. in the rotaries and 3 per cent. in the transformers. The sub-station apparatus is at its highest efficiency at the time of greatest loading, when the feeder lines are at the lowest efficiency and thus have a favorable effect on the load line.

The losses on railway feeders vary from 10 to 25 per cent. Often there is sufficient copper if rightly distributed and tied together to reduce this at least one-half. Such a change would also improve the load factor and increase the efficiency of the station. The losses in the motors and car apparatus have already been referred to in this paper, but actual data and tests are here introduced in evidence.

From a large number of tests made on the trains of the Metropolitan Elevated Road, the following have been selected as illustrating this part of the subject. The trips are numbered from one to eight, and in the table below the data for each trip are given, together with the general results obtained. All of these

No. of trip........	1	2	3	4	5	6	7	8
No. of cars in train	4	4	4	3	3	2	2	4
Total time of trip..	28'26"	29'03"	28'30"	28'37"	27'26"	25'30"	23'48"	32'44"
Total time of stops.	2–19	2-05	2–42	1–47	1-16	0-54	1-22	1 41
Time running.....	26–07	26–58	25-58	26-50	26-10	24-36	22-26	31-03
Average speed (including stops)....	13.3	13.0	13.2	13.88	14 4	14.9	15.9	11.53
Average speed (not including stops)..	14.4	14.0	14.5	14.7	15.1	15.3	16.8	12.2
Average current (including stops).	138.3	142.6	138.6	130.2	129.5	90.1	106.6	101.1
Average current (not including stops)...........	148.7	153.2	151.8	137.4	135.6	92.5	112.4	106.4
Average volts (at the train)........	504	498	503	512	516	521	520	509
Efficiency from generators to car axles............	51	50.5	52	50	51	51.5	50	47.5
Kilowatt hours per car mile (at the train)............	1.32	1.36	1.32	1.69	1.62	1 58	1.76	1.11
Kilowatt hours per car mile (at the station)..........	1.44	1.52	1.44	1.81	1.68	1.67	1.69	1.21

runs were made on a dry track, in moderate weather and under average working conditions. The total electrical energy at the train was measured by Thomson recording wattmeters and the voltage and current by Weston instruments. The velocity record was taken from a Boyer speed recorder and the stops and average speed from a double set of stop-watches. The pressure at the station was measured by a recording voltmeter.

Trip No. 1 was made from Franklin street over the Logan Square line with a four-car train, heavily loaded, making an average running time of 13.27 miles per hour. The maximum grade on this line, going west, is 0.75 per cent. ascending for about 2,350 feet, and descending for about 1,950 feet. Other grades do not exceed 0.03 per cent. and only extend short distances. Current and speed diagrams on a time basis are plotted in Fig. 13 for trip No. 1. The current is the total amount taken by the train for power, and an inspection of the diagram will readily show the point of passing from series to multiple. The amount of energy required or absorbed by the train is as follows:

Total energy for accelerating the train	30,940,000 ft. lbs.
Total energy for train resistance	14,110,000 ft. lbs.
Total energy for grade	3,400,000 ft. lbs.
Total energy required for propelling the train	48,450,000 ft. lbs.

Per cent. of energy for accelerating	63.9.
Per cent. of energy for train resistance	29.1.
Per cent. of energy for grade	7.0.

Time of trip, including stops	28 min. 26 sec.

Average H. P. required for propelling train	51.5.
Average amperes of current	138.25.
Average volts at train	504.
Average watts at train	69,678.
Electrical horse-power transmitted to the train	93.4.
Average volts at the station	545.
Average watts at the station	75,346.
Electrical horse-power at the station	101.
Efficiency from electrical generators to car axles	51 %.

Assuming the commercial efficiency of the generators as 93 per cent. the total power required at the engine shaft, to propel this train, is 108.5 horse power.

Trip number 2 was made with a four-car train, under similar conditions to trip number 1. A current curve on a time basis is given for this trip in Fig. 14. In all of the current curves, it is easy to distinguish by inspection when the motors are in series and when in multiple. The steps on the controller are also distinguishable by the greater peaks on the curves. The smaller peaks and other irregularities are due, principally, to changes in voltage, caused by other trains in the same section, taking more or less current.

Trip No. 3 was made under similar conditions to trips 1 and 2, and the data and results are given in the table.

Trip No. 4 and 5 were made with heavily loaded three-car trains and the results are set forth in the table. Both the speed and commercial efficiency of apparatus are higher than in the case of the four-car trains. A diagram of current on a time basis for trip No. 4 is given in Fig. 15, and a speed curve on a distance basis in figure 18.

Trips No. 6 and 7 are with two-car trains and show a higher speed than attained in the case of the three and four-car trains. The greater amount of power consumed in trip 7 is due, mainly, to the increased speed over trip 6. A current curve for the latter trip is shown in Fig. 16, and a speed curve in Fig. 17.

Trip No. 8 was made with four loaded cars and the motors operating only in series. Both the speed and current are less than for similar trips with the motors operating in series and multiple. The percentage of power saved is greater than that of the reduction in speed, but this is due, not to a better efficiency of the apparatus at lower speeds, but to the fact that the amount of power required to propel a train making many stops, decreases more rapidly than the average speed. The current diagram for the trip is given in Fig. 17.

The amount of power lost in the machinery and line, as indicated by the commercial efficiency of the apparatus given in the table, might seem at first thought to be large, but considering the transformation and the distance of transmission, it is certainly not excessive. The loss in this respect is offset by the smaller cost of producing energy by power-house methods. The train weight also may be reduced with electric power to a point impossible with steam locomotives, and the rate of acceleration increased, and thus a saving effected in power used at the train. While this does not improve the efficiency of the transmission, it reduces the total amount of power required, and as a feature of the system, it should be given due credit.

Electrical energy can be produced in the vicinity of Chicago, with cheap coal, under the conditions of a railroad load, at less

FIG. 13.

FIG. 14.

FIG. 15.

FIG. 16.

FIG. 17.

FIG. 18

FIG. 19

than half-a-cent per kilowatt-hour, and in the form of mechanical energy at the car axles, costing about one cent per kilowatt-hour, it is several per cent. cheaper than it can be generated by steam locomotives. Add to this the actual saving in energy from a more rapid acceleration and from reduced train weight, and the total direct advantage for the electrical system is obtained as far as economy in power is concerned.

While any reduction in the cost of power (not only for fuel, but repairs, labor, water, oil and waste, etc.) is of great importance to railroads, the many other advantages of electricity, representing betterments of the service and greater earning capacity are the chief qualities which will determine its adoption in any case in place of steam locomotives. As a motive power electricity is simple, efficient and wonderfully flexible, and it is hardly wise to predict its limitations.

DISCUSSION.

THE PRESIDENT:—Gentlemen, this paper is a most timely one and given to us in truly professional form. I think we can consider ourselves as owing a special debt of gratitude to Mr. Gerry. It is the very kind of paper that those of us who have to do with getting papers are anxious to secure.

DR. PERRINE:—I have recently been talking with Mr. Sprague about this problem of electric railroading, and on account of some of his ideas I regret exceedingly that he is not here to-night, and I would like to speak on some of the points to which he has called my attention. In the first place, Mr. Sprague holds that the simple question of cheapness would not be one which would entitle a heavy road, such as an elevated road, to substitute electricity as its motive power. He makes the statement, that seems to me to be rather extreme—nevertheless we understand that he generally knows what he is talking about—that if on the elevated railroads of New York a system of power were applied which would lead to the hauling of one more passenger, per car, per station, in each train, the added revenue so acquired would amount to more than saving one-half the coal bill as at present used, and starting from this premise, what is demanded from the application of electricity to steam railroading is not so much cheapness, as increased facilities. He attaches even more importance to the rapid acceleration of trains than is attached to it in this paper, where it shows that the rapid acceleration reduces the total amount of energy required to move across between two stops a certain distance apart, and in order to accomplish this Mr. Sprague is now attempting to control from one end of the train a series of motors all located on the separate cars; so that not only do we have the track adhesion of our locomotive car, but with any loaded trains we have the track adhesion which may be given by the entire weight of the train, and particularly on grades and curves this facilitates the rapid handling of trains. It seems to me that too much importance cannot be attached to this question of the rapidity of acceleration, for rapid acceleration means not simply the reduction in the amount of power necessary to move a train, but it means what is of still greater importance, the facility of getting trains out of the way and permitting new trains to come in. In other words it means the handling of the whole service on shorter headway, and in consequence of a greater possible number of trains, the handling of a definite amount of traffic with a less concentrated load on the structure, and also a more satisfactory service which will induce increased travel. This line of argument seems to me to be of very great importance. As I said, I am exceedingly sorry that Mr. Sprague is not here to-night to give us his ideas in his enthusiastic way, but this much I gathered, and coming together with this paper, it shows that the two engineers are thinking a great deal along the same lines and that adds to the interests of the conclusions.

THE PRESIDENT:—I might add to what Dr. Perrine has said, that Mr. Sprague mentioned to me another advantage of the system which he advocates, and that is that you could maintain the same headway all through the day by simply reducing the length of trains for periods of light load, and he thought that would be a great factor in retaining the trade; that is to say, during the middle of the day the trains are run at long intervals; many persons get into the habit of using other means of transportation, whereas if you could keep up the same headway the public would become accustomed to using the elevated roads at all times. I believe that has been found to be one difficulty—the long intervals in the middle of the day impress people unfavorably in regard to the elevated roads, and he brought that out as one of the strong points of motor cars, which enable the trains to be made up of any number of cars and easily increased or decreased. That system certainly seems to possess many advantages.

THE SECRETARY:—The question of headway is of considerable importance in retaining the traffic, as many of us know from personal experience. One of the objections always raised to suburban traffic is, that one has to be governed by a time table, while on the Manhattan Elevated Railway one gets into the habit of starting when he is ready and waiting for a train. The difficulty of infrequent trains also occurs at night, at least after the theatres close. I suppose it is expected that everyone should be at home by that time. One goes to a station expecting to catch a train, and will have to wait perhaps fifteen minutes. That is rather objectionable when it gets to be twelve or one o'clock at night and the passenger is going out of town and has to make a train connection. Furthermore the management is not very particular about informing people as to the exact headway under which trains are run, and the consequence is that one is in entire ignorance as to when a train may be along, as no proper announcements are made that the trains are to be changed from a ten minute headway to a fifteen minute headway or whatever it may be. And that leads up to the manner in which they endeavor to accommodate their light traffic by taking off trains, and of course the more trains they take off the lighter the traffic becomes, because in New York City the elevated is paralleled by the cable road which at night is practically as quick and the cars more frequent.

PROF. THOMSON:—I happen to know of this suggestion of Mr. Sprague and there is no question whatever but that the advantages pointed out exist. There is just one remark to be made however in that connection, that complexity is introduced by having the cars all equipped with motors, and the difficulties of making connections from car to car are greatly increased of course in coupling; so that it may become a serious question as to whether we are not paying too much for some of these advantages; whether in other words we ought to extend the complexity so far as has been proposed, to obtain the advantages which follow, or whether there is not some other way out of it. Each car, as I understand it, would have to be possessed of a controller system of its own, and that controller manipulated by some automatic mechanism from the head of the train. Of course this means a good deal of change of mechanism, some of which may get out of order and a few stoppages might be of more serious import to the success of the road than the disadvantages of having a simpler mechanism which did not fufil so many conditions.

MR. DUNN:—I believe Mr. Sprague expects that even if the mechanism on one car or two cars does get out of order that the others will carry it right along, and he hopes by that means to reduce very largely that chance.

MR. C. P. STEINMETZ:—The problem of elevated railroad service is becoming exceedingly important at present. This is a city railroad service of high speed with very frequent stops, at intervals from 1500 to 3000 feet.

Some very interesting theoretical investigations of this problem have been made by one of my assistants, Mr. A. H. Armstrong, and will be published in due time, and since I had occasion to find the results checked by practical experience, I shall give a few of the conclusions, which by the way are brought out quite prominently by this paper also.

The elevated railroad service differs from all other railroading by the feature that the motors never run at full speed, but that the whole trip practically consists in acceleration and retardation. That is, the distance between stops is usually so short that before the train has reached the full speed of which the motors are capable, the brakes have to be applied for the stop at the next station. Thus the speed curve of such a railroad trip is as shown in the solid line in Fig. 20. This curve represents a run of 2000 feet in 70 sec. or an average speed of 19.5 miles per hour. As accelerating efforts are used, 100 lbs. per ton; as friction 10 lbs. per ton, and 150 lbs. per ton train weight as braking effort.

As seen, the train accelerates for 31 sec., reaching a maximum speed of 30.5 miles per hour. Then the power is turned off and the train runs on its momentum, that is coasting, until 52½ sec. after the start the brakes have to be applied and the train brought to a standstill for the next stop. By changing the amount of acceleration and retardation the speed curve can be varied to a considerable extent. Four such curves are shown in Fig. 21.

As seen, the lowest acceleration at which the distance can be covered in schedule time is 87 lbs. per ton. With this value, acceleration has to be maintained for 46.5 seconds and immediately after the brakes have to be applied, that is the range of coasting has entirely disappeared and the maximum speed reached by the train is 38.2 miles. The more rapid the acceleration is, the shorter time is needed for accelerating, and the more time available for coasting, and at the same time the maximum speed reached by the train decreases to 30.5 miles per hour at 100 lbs. acceleration, 27.2 miles per hour at 150 lbs. acceleration, and 24.8 miles per hour in the theoretical case of infinite acceleration, that is if the train could be brought up to maximum speed instantly.

One very interesting feature regarding the total amount of energy consumed by the train during the trip is brought out by these curves. With the change of the rate of acceleration, the maximum speed of the train changes from 24.8 miles per hour at infinitely rapid acceleration, to 38.2 miles per hour at the lowest permissible acceleration, that is in the proportion of 1 to 1.54, and consequently the kinetic energy of the train in the proportion of about 1 to 2.4, and the energy put into the train for acceleration in a still somewhat larger proportion, since at the lower acceleration, the time of acceleration and thus the friction loss during this time is greater.

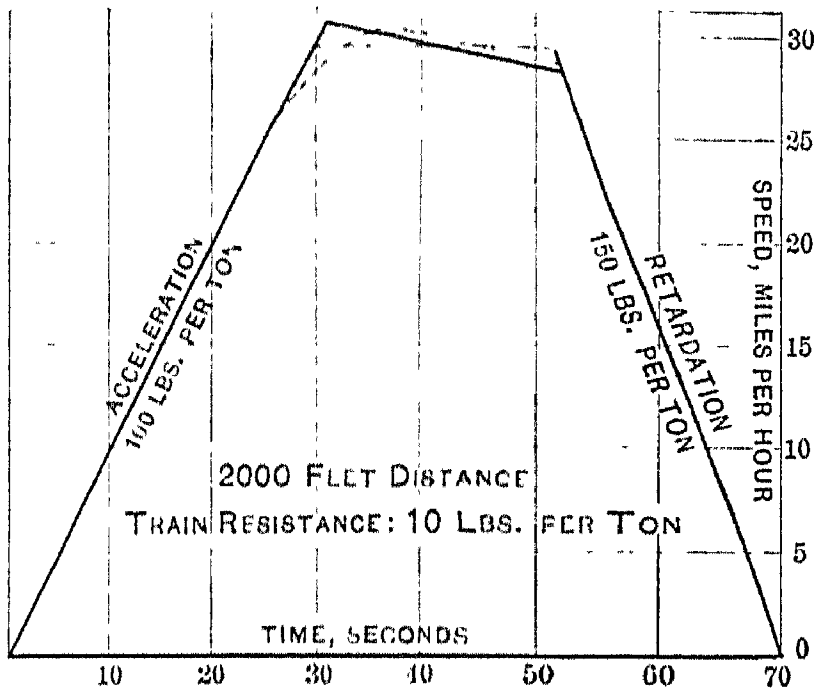


FIG. 20

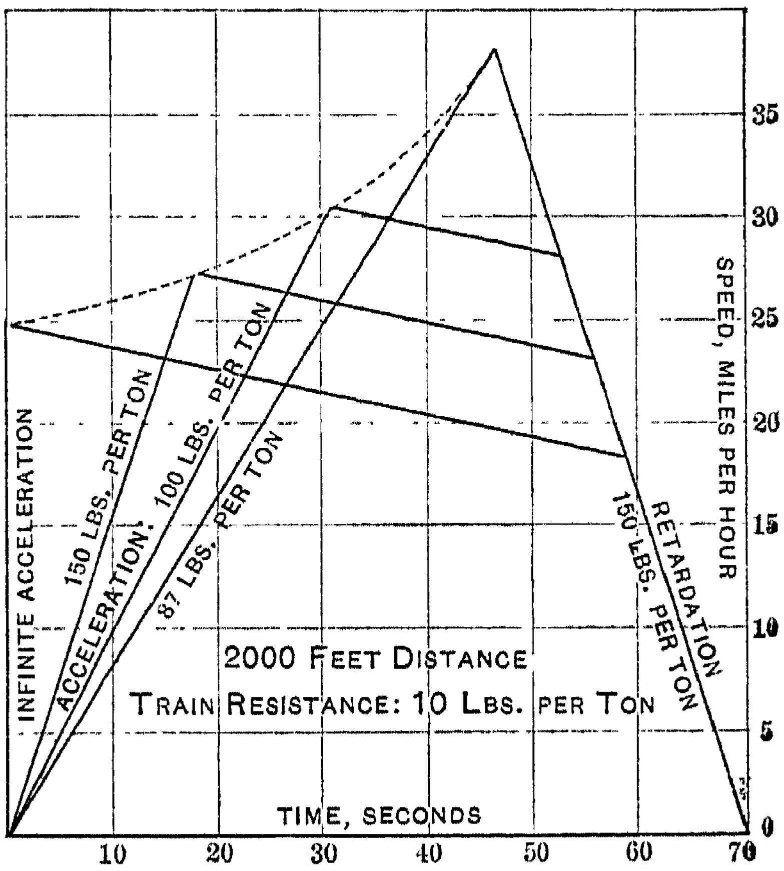


FIG. 21

Since the power put into the train up to the point of maximum speed represents the total energy required to cover the distance in schedule time, it follows that by varying the rate of acceleration the energy consumed by the train can be varied in the proportion of 1 to more than 2.4, or in other words with the slowest possible acceleration more than 2½ times (allowing for friction during acceleration) as much energy is required as would be necessary at infinitely rapid acceleration, or in other words the more rapid the acceleration of the train the less energy is required to cover the distance in schedule time,—but at the same time the larger must be the current and power put into the motors during the time they are in operation, etc.

A lesser maximum speed than necessary during a run consisting of acceleration, coasting and retardation, can be reached with a given rate of acceleration and retardation by a run consisting of acceleration, running at constant speed and retardation.

The efficiency of the latter run, however, is considerably lower than in the former, as seen by comparing the two speed time curves a, b, c, d, and a, b^1, c^1, d in Fig. 22. At the same schedule time the areas of the two speed curves a, b, c, d, and a, b^1, c^1, d are equal. With the speed curve a. b, c, d, consisting of acceleration, running at constant speed and retardation, the total power put into the train is the acceleration up to speed b, c plus the power consumed by friction from a to f.

With the speed curve a, b^1, c^1 d, consisting of acceleration, coasting, and retardation, the total amount of power put into the train is that giving the train momentum at speed b^1 e^1 plus the power consumed by friction during the time from a to e^1, that is the time during which the motor is in circuit. Thus in the first case the power input is less by acceleration from b to b^1, but more by the friction loss from e^1 to f. This friction loss, however produces retardation from b^1 to g and thus is equal to the acceleration from h to b^1 (where h g is parallel to a d). Hence in the case of running at constant speed, the power input exceeds that of the case of coasting with the power shut off, by the power consumed in the acceleration from h to b.

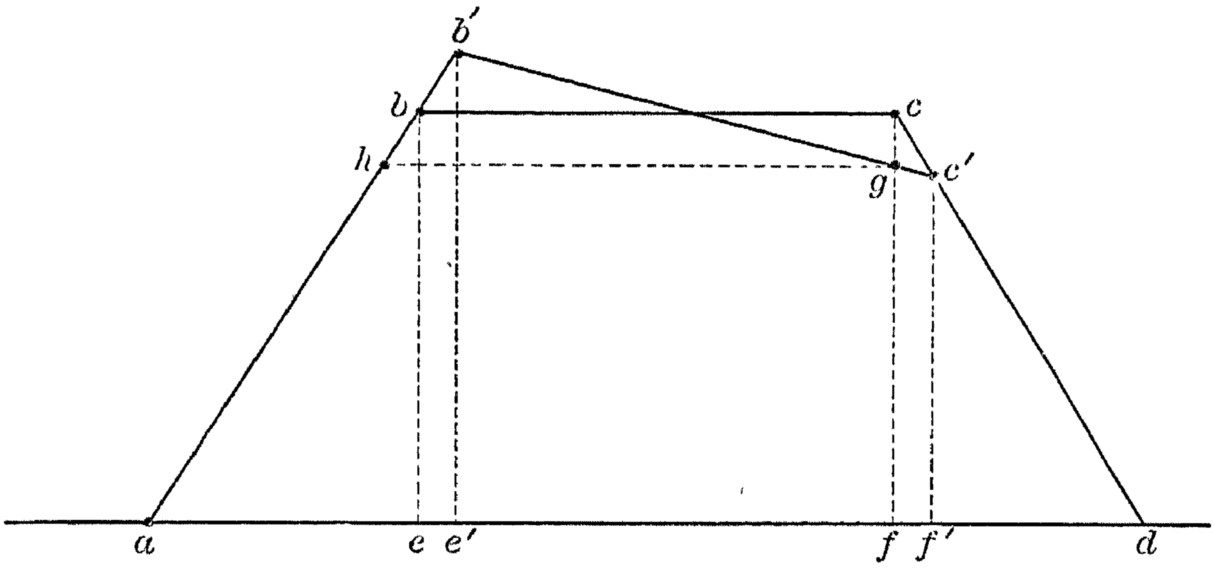


FIG. 22

In another way this can be seen thus: The total power input during run is equal to that consumed in the brake during retardation, plus that consumed by friction. The power consumed by the friction is the same in any case. The power consumed by the brakes, however, is less in the case of coasting in which the brakes are applied at a lower speed, than in the case of running at constant speed, and consequently the economy of operation is higher in the first case.

Thus it is theoretically uneconomical to leave the motor in circuit after the period of acceleration is passed, and run at constant speed. In practice the run at constant speed is still much inferior, due to the low efficiency of a motor built for high acceleration and running at speed, that is at very light load, and it is therefore preferable to accelerate and then coast until the brakes have to be applied.

A slight gain can be reached by dropping the acceleration off slightly near the maximum speed, in running "on the motor curve" as shown in dotted line in Fig. 20. During the whole part of acceleration at constant torque, a greater or lesser part of the voltage has to be consumed in the rheostat, since without rheostat or equivalent means, the series motor cannot maintain constant torque at constant voltage but varying speed. This loss in the rheostat can be reduced partly by having the rheostat cut out completely somewhat before maximum speed is reached, and accelerate during the last part of acceleration on the motor without rheostat, that is with an accelerating effort decreasing with the speed. The permissible range of acceleration on the motor curve, that is without rheostat, is very short, however, since the torque drops off quite rapidly with increasing speed, and in practical operation sufficient margin must be left in the motors to carry a somewhat larger load, as at times of unusually heavy traffic, or to "make up time."

Thus the faster the acceleration the less energy has to be put into the train to reach the maximum speed needed to cover the distance in schedule time, and to be wasted afterwards in retardation, that is to be consumed by heating the brakes and grinding up the car wheels. Here then is an enormous chance for improvement, since by far the largest amount of power in elevated service is merely used to set a heavy mass in motion and afterwards wasted by destroying the motion again. A very ingenious method to use a part of this energy, although not applicable to most elevated roads, will be applied in the Central London Subway Railroad, where they intend to run heavy trains every $2\frac{1}{2}$ or 2 minutes. Their underground stations are built on what may be called hills, that is the road-bed is not on a level but rises to the station, so that when a train leaves the station it runs down a fairly heavy grade and gravity is used to accelerate the train, and in approaching the next station the up grade towards the station is used to retard the train, hereby less electrical acceleration and less retardation by brakes is needed, and motors as well as brakes greatly relieved, and it is estimated that in this manner about $\frac{1}{3}$ of the power will be saved.

Referring now to the ability of exceedingly fast accelerations by a very great subdivision of motors. Undoubtedly a considerable advantage is gained by making as many axles driving as possible. I doubt, however, whether it is necessary to have all axles driving. In elevated service the limit of permissible acceleration is probably not the adhesion of all the axles but the comfort of the passengers, and before you strike the limit of adhesion of even half the axles or less, you probably reach the point where acceleration is so rapid as to be too uncomfortable to be permissible.

Dr. Perrine:—The two first statements of Mr. Steinmetz are liable to confused interpretation, and I think that the statements of the paper are also liable to the same interpretation. Taking the second first, as being the simpler, Mr. Steinmetz says that acceleration as now practiced in electric railroading or in street railroading in general is as rapid as comfort will allow. I think by examining Fig. 4 page 359 you will see that it is not so, because one can stand just as rapid acceleration as retardation. Whereas the total retardation is in about 25 seconds, the total acceleration is in something over 60 seconds, which shows that we have a possibility, still within comfort, of a great deal more rapid acceleration than at present. The second thing he said was that the paper showed that the more rapid the acceleration the less was the power. This apparently contradicts his statement that the history of running a train between stations was simply acceleration and retardation. Thus this statement should be qualified to avoid misunderstanding. His meaning obviously was that in elevated railway service the motors never reach the constant speed at which they could run without rheostat, but that before this time the acceleration has to cease, and the speed be maintained constant by a rheostat, or the motor cut off and the train run on its momemtum, that is retarded by the train friction, until the brakes are applied. There should be a time between acceleration and retardation by the brakes, as shown also in the curves given by Mr. Steinmetz, and the value of the rapid acceleration consists almost entirely in the fact that with the same time between stations we can actually bring our train up to speed, and remove the condition that the whole history of the train between stations is acceleration and braking.

MR. STEINMETZ:—Referring to Figs. 3 and 4 of the paper, while the total amount of time used for acceleration is considerably greater than that of retardation, you see that the first part of the acceleration curve is practically as steep as the retardation curve, thus this rapid initial rate should have been kept up during the whole acceleration and considerable power would have been saved.

I fully agree with Dr. Perrine that the most efficient way is to accelerate as rapidly as permissible until you have reached sufficient speed to carry you to the next station in schedule time, then coast until it is time to apply brakes in approaching the station. It was this very condition of economy which I tried to explain in my former statement as superior to the method of leaving the motors in circuit and accelerating until the brakes have to be applied for the next station.

PROF. THOMSON:—The desirable thing to do it seems to me, would be first to get energy into the train rapidly. Your prime object is to get an average speed which will consume a certain time between stations. If therefore, you can have your acceleration rapid and then coast the whole of the rest of the distance, of course, that means the best possible condition, because the energy put into the train is represented simply by the consumption up to the end of acceleration. Now if, on the other hand, you simply reverse the diagram, getting the same average speed, you accelerate far more slowly: you consume the same amount of energy during that time: you store it up in the train and you now waste it all at the same rate you put it in before, by braking. Thus you have the same average speed maintained, and the same time consumed: but in one case a very rapid acceleration and coasting to the other station: whereas, in the other case the acceleration is very slow and a sudden braking. But of course in practice that may not fit the conditions. It may require too high speed to be maintained or too high an acceleration, more than can be obtained, so that the next best thing we can do is to get as high speed as is permissible at first, run along and come out at the end so that we have to use as little braking as possible: possibly putting on power again in case the speed fails to be maintained as is needed. Of course, the system must be flexible, and we do not ever hope to meet the theoretical conditions, but we must approach them as near as practice will allow. The point is, to determine what is the theoretical condition, and then see how nearly we can come to it in actual practice.

THE PRESIDENT:—It seems to me that the problem from a mechanical point of view is an extremely simple one. The fact that the author considers paradoxical, is simply this; that if you had an infinitely rapid rate of acceleration to a given speed and then an infinite rate of retardation as suggested by Mr. Steinmetz, and leaving out the question of stops, you would get the most economical condition, and hence the kinetic energy put into the train would be a minimum.

The following paper on "The Cost of Steam Power, by Mr. H. A. Foster," was read at the morning session, July 28th, by the Secretary, in the absence of the author:

A paper presented at the 14th General Meeting of the American Institute of Electrical Engineers, Eliot, Me., July 27th, 1897. President Crocker in the Chair.

THE COST OF STEAM POWER.

BY HORATIO A. FOSTER.

In this age of electricity, when so much is being done in the way of developing its applications, and especially in its application to the transmission and distribution of power, perhaps no one item causes so much controversy as the cost of steam and other familiar forms of power. It seems to have been taken for granted for years that anyone and everyone knows the cost of developing power by steam, and in almost all cases when a person stating such costs is pinned down to facts, it has been found that he is either guessing, or quoting those he supposes are authorities. It is to be presumed that statements of actual tests for cost might have been published, but the writer has in a somewhat extended search run across but one such statement that might be considered reliable, and that was a test for something under 100 days, and that practically confined to the warm season of the year and not therefore of the greatest value.

Other estimates have been made from extended experience and carefully revised theory, and in fact little can be added to tables published during the past few years by some of our most eminent and best qualified engineers, in the way of carefully prepared estimates of what should perhaps be called the average cost of producing steam power under various conditions as to amount of power and the type of machinery employed.

It must be said, though, that almost all these estimates have been made for powers of large size and where little variation of load takes place, and, while such estimates are of great value for use in discussion of the subjects, the writer has found them somewhat unsafe to use unless their results are applied in connection with extended experience, for, while the results considered as averages are probably correct for ordinary conditions, they cannot of course be expected to include extraordinary conditions, and the results of this investigation seem to show that individual cases vary so much that it is not fair, and may be misleading to state average costs.

It seems a pity that the cost of power is most often quoted for one horse-power for one year, and so freely assumed that there is an average cost of power on which one can base estimates in the cost of manufacture; for the writer will endeavor to show, as this paper progresses, as others have done, first, that any general statement of the cost of power per horse-power per annum is incorrect, for the reason that such a statement does not ordinarily take into account the number of hours run per diem, or the number of days per year, and even in that class of plants supposed to run, say 308 days per annum, it is seldom one can be found that runs a full year, and no two run the same length of time; and second, that no such statement of an average cost of power is of any value whatever, unless it be for plants employed in similar work, and under exactly similar conditions, and even then the amount of power developed is such a factor for varying the unit cost that it is in the opinion of the writer quite fair to say that there is no average unit cost for steam power, that is safe for general application, and it is thought that a somewhat careful study of the tables and computations accompanying this paper will help to a clearer understanding of the reasons therefor.

Although in the great majority of instances office accounts are so kept as to give no real basis upon which to compute the cost of power, and in most off-hand estimates, the rated capacity and not the average power developed has been used as a divisor, there can be no doubt that in some of the older industries, say in the great flour mills and the large eastern cotton factories, where prices of manufactured goods have been tending downwardly for so many years, and very close accounts of unit cost have necessarily been kept, and, as in all other departments the power has been very carefully looked after, that in such cases it is very likely that careful comparisons will show the cost of power to be more or less uniform when used under similar conditions, but reference to the tables will show this to be more widely at variance than is commonly thought.

It will be the endeavor of the writer to show by tabulated data as far as possible, the condition of the plants tested, without going any more into detail than seems necessary for a clear understanding.

In order that the value of the results may be determined, it is necessary to give some description of the methods pursued in obtaining them, and, as they were as far as possible the same throughout, a general description will do for all except the special cases.

In order that the greatest value might be obtained, it has always been the opinion of the writer that no results for a period short of twelve consecutive months should be used, and in all but one case which was for eleven months, a year has been taken as the smallest unit of time.

In a general way, the unit of time having been settled, where possible a unit of output was selected, after a careful and somewhat extended study of the special business in all its conditions, on which averages could be constructed and which could be turned into horse-power after determining its rate.

Indicator tests were always made both for determining the rates of power and the ratio of power to the unit of output: for instance, in a flour mill it is only necessary to apply indicators to the engine cylinder for a certain period of time, not less than 24 hours, and to count the actual output in barrels, to determine a fairly accurate ratio of horse-power per barrel of production, after which it is a simple matter to determine the average for a year from a total production and the actual time during which the mill was running and the output recorded; or in an arc lighting station, if an indicator test is made of the engine for the entire time per day, during which lamps are burned, and the number of lamps running during the same period be recorded, then also it is easy to determine the ratio of power to lamps, whence by computation from the records kept of the number of lamps burning and the time in hours during which they were lighted for a year, the lights can be reduced to horse-power, and if accurate and well classified records of expenditure are kept, the annual and hourly cost of power is determinable to a close degree of accuracy. Of course, wide variations in the amount of power used will often change the ratio, but care has been taken in these tests, not to base them on periods of changing power consumption, and it is therefore thought that the results are within the ordinary limits of accuracy.

For the sake of uniformity, as well as to reduce the items of account to as small a number as was considered consistent with clear understanding, a list of cost accounts was determined on, that in most ways agrees with work previously done in this line, and which it was thought could be most easily met by the most ordinary bookkeeping.

The list is as follows:

Operating Expenses.
  Fuel.
  Wages.
  Supplies.
  Repairs.
  Water.
  Incidentals, including lighting and removal of ashes.

Fixed Charges.
  Interest on cost of plant.
  Depreciation on value of plant.
  Insurance.
  Taxes.

In considering the value to be given to each item, many things had to be discussed in order that proper separation of expenditure due to items other than for power could be made, as for instance the item of fuel; in many cases buildings have had to be heated, either by exhaust or live steam; steam has been used for hot tables, as in the case of newspaper offices, and for dry rooms for lumber etc. as is the case of a furniture factory. In all such cases the study of the plant, consultation with the engineer in charge and the management, coupled with the experience of the writer has ensured the determination of an amount satisfactory to all concerned as being the nearest correct obtainable under the ordinary conditions of practice.

In the item coming under the head of fixed charges, a somewhat different treatment obtained, as so little attention is given these items by the ordinary business management that in most instances not only the value of the plant, but the items going to make up the fixed charges had to be determined by the writer from his experience, together with such information as could be gotten from the people in charge. While insurance and taxes were of course determinable from the books, interest was rated in almost all cases at 5 per cent., and depreciation at rates varying from 2½ to 10 per cent. for building, and 5 to 15 per cent. on steam plant, all according to type of material in use, its condition, the manner in which it was handled, etc. In but few cases were either of these items considered in the estimates of cost by the owners. It must be remembered in this connection, that fixed charges go on all the time, 24 hours per day for 365 days, and that the unit cost is the same if computed by the year, but does not have the same relative value when computed by the number of hours the power was actually in use. In passing, it may be well to say that the number of firms in good business standing that are entirely at sea regarding the actual cost or present value of power plant is to say the least astonishing.

One item taken into consideration in all the tests, and one seldom considered at all in the ordinary statements of the cost of power, is the value of the building or part of the building devoted to the use of the power plant. In some few cases buildings were set apart for this purpose, and where the value was known it was of course easy to fill out the item; but in cases where the power plant was in the same building with the other portions of the plant, it became necessary to set off the value from the rest, and this was most often done by determining the renting value of the room used, which can usually be done with small chance of error, and then to capitalize the rent as the value of that part of the building devoted to power purposes.

In one item used in these tests, the writer apparently differs from most other estimators of the cost of power, and that is in the use of the indicated horse-power rather than brake horse-power for the divisor, and his reasons for using it are as follows: viz:—Indicated horse-power can nearly always be determined to a degree of accuracy only limited by the usual errors of instruments and their users, generally conceded to be small; while brake tests can seldom be made in practice, and the net power is therefore most often determined by assuming a certain percentage of engine and shafting efficiency which under general conditions is quite incapable of proof, and the errors of which must be added to those of the indicator test. The writer therefore prefers to eliminate this chance for error, and should any one desire to change the figures here displayed to brake horse-power, it is only necessary to make the single computation due to any engine efficiency that he may wish to assume.

Referring now to plants tested, those on which reports were made were not selected in order to show the very considerable variation in results that are given, but for availability and for variety of types and of business.

The plants on which tests were made for unit cost of power were:

Two Electric Lighting Stations.
One Grain Elevator.
Three Water Works Pumping Stations.
Two Flouring Mills.
Six Cotton Mills.
Four Newspaper and Printing Offices.
One Department Store.
One Furniture Manufactory.
One Bakery.
One Glazed and Fancy Paper Manufacturing Company.

The criticism may be offered that not enough plants were tested in any one business to determine an average cost of power in that business, and a careful inspection of the following tables will show that comparisons of cost of power between unlike types of business are of little value, and if still further comparisons be made, it will be found that conditions vary so much in the same type of business as to show that any statement of an average cost of power even there is quite misleading and that therefore tests of even a single plant of any of the different classes of business is of value only so far as it determines the cost for that plant alone, and demonstrates the fact of which the writer has become thoroughly convinced, that each plant must be tested as if it were the only one of the type in existence.

Coming now to tables, table I for easy reference, gives the number of the plant, the number and type of boilers, with all their dimensions, and the nature and cost of fuel used.

Table II is a continuation of table I, stating the number and type of engines used with all cylinder dimensions and rated power: the total plant value with the value per rated horsepower; the number of men employed with their average wages, and remarks on the use of steam for purposes other than for power, when taken from the boilers supplying the engines.

The above tables, perhaps, need little explanation, as all items are placed in columns so that results shown in other tables can easily be traced back and possible reasons for the conditions be shown in the plant equipment or the way it may be handled.

TABLE I. POWER PLANT EQUIPMENT. BOILERS AND FUEL.

No. of Plant.	BOILERS.									FUEL.	
	No.	Type.	No. shells each.	Diameter shells in inches.	Length of shell in feet.	No. tubes.	Diameter tubes in inches.	Square feet grate surface.	Steam pressure carried pounds.	Kind Used.	Average cost per 2,000 lbs.
1	2	Vertical, fire tube.......	1	96	14	270	2½	54	125	Soft Slack......................	$2 01
2	2	Horizontal return tube..	1	60	16	48	4	20	80	Soft run of mine and slack..........	1 82
3	1	Horizontal return tube..	1	72	16	86	4	36	80	Pea and Nut Anthracite..........	2.25
	2	Horizontal return tube..	1	54	12	52	3	18	80		
4	1	Horizontal return tube..	1	48	12	58	3	..	90	Natural Gas......................	Per month
	1	Horizontal return tube..	1	60	14	78	3	..	..		
5	1	Horizontal return tube..	1	60	13	64	3½	22⅓	60	Soft Nut and hard Screenings......	1.94
6	2	Horizontal return tube..	1	60	14	58	3½	25	75	Soft Coal. Yough................	2.00
	1	Horizontal return tube..	1	48	12	54	3	16	80		
7	4	Water tube. "B. & W."	2	42	18	126	4	119	140	Hard and Soft Slack..............	1 45
	2	Water tube. "Geary."	1	44	21⅔	139	4	42	140		
	6	Water tube. "National"	1	38	18½	60	4	27	140		
	1	Corliss Vertical.........	1	108	18½	264	3	50	140		
	1	Marine................	1	86	20	200	2	38	140		
8	2	Horizontal return tube..	1	60	14	98	3	25	90	Soft and hard Slack and Screenings.	1.77
9	20	Horizontal return tube..	1	60	16	66	4	30	70	Soft Coal. Estimated.............	2.00
10	2	Horizontal return tube..	1	72	16	100	3½	27	80	Soft Coal........................	1.95
11	4	Horizontal return tube..	1	60	16	54	3½	28	80	Soft Nut and Slack................	
12	2	Horizontal return tube..	1	72	16	92	4	25	80	Soft, Nut and Lump Coal..........	2.32
13	2	Water tube. "B & W."	1	33	18	48	4	Roney	110	Soft Nut Coal.....................	2.00
14	1	Horizontal return tube..	1	54	14	52	3	18	70	Soft Coal and Slack...............	2.05
	1	Horizontal return tube..	1	54	14	64	3	18	70		
15	1	Horizontal return tube..	1	52	12	68	3	25	75	Soft run of Mine Coal.............	1.90
	1	Horizontal return tube..	1	54	12	64	3	25	75		
16	1	Horizontal return tube..	1	72	14	86	4	..	85	Shavings and a little..............	
	1	Horizontal return tube..	1	72	12	86	4	..	85	Soft Coal.........................	
17	6	Vertical, fire tube.......	1	60	15	180	2½	28.3	150	Soft Coal.........................	3.35
18	8	Horizontal return tube..	1	66	20	72	3½	25	95	Half each, Hard Pea and Soft Coal	2.55
19	11	Horizontal return tube..	1	60	20	78	3	30.2	100	¾ Soft, ¼ Rice..................	2 68
	5	B. & W.................	3	36	23	126	4	60	70		
20	6	Harrison safety.........	..	..	..	...	..	40	100	150 H. P. each. Buckwheat.......	2 40
	8	Harrison safety.........	..	..	..	...	..	38.3	110	150 H. P. each. Buckwheat........	2.40
21	9	Vertical, fire tube.......	1	60	15	184	2½	28.3	120	½ Soft, ½ Pea and Rice hard......	2 57
22	8	Horizontal return tube..	1	66	16	124	3	30	125	Cumberland Coal.................	3. 0

It will be seen that in rated capacity the plants vary from 40 horse-power to 2,500 and in value per rated horse-power from $23 to $89 in steam power plants, or as high as $368 in water works pumping stations.

While the type of boiler used leans largely to the plain, old-fashioned return tubular, with the exception of the cotton mills, the types of engines are almost as varied as the number of plants.

In fuel, soft coal or slack of soft coal largely predominates, and a considerable use of mixtures of the latter with dust from the yards and hard coal slack will also be noticed, which is largely due to efforts to reduce the smoke nuisance.

In table III, under the general heads of "out-put," "operating expense" and "fixed charges," are shown all the items in detail for each plant, going to make up the total annual cost of power, and in table III a, will be found the items making up the cost per horse-power per hour.

The first column in table III, under "output," shows the average power developed for one year covering the number of days and hours per day shown in the third and fourth columns; and column 2 shows the percentage of the total rated capacity that the average power actually developed bears to the rated horse-power of engines, as shown in table II. The time in hours per day shown in column 4, is not in all cases the actual average per day for the year, but the regular time on which the plant was run during the year under consideration, therefore multiplying the figures in this column by the days actually run will not in all cases give as a result the total hours per annum shown in the sixth column, which are the actual hours run in each case.

In table III, under the headings of "operating expense," "fixed charges," and "cost per horse-power," the figures are the costs per annum for each item, while table III$_A$, gives the cost per horse-power per hour obtained by dividing the annual cost of each item by the number of hours run as shown in the sixth column.

In tables II, V and VI, the results from the different plants have been separated and classified according to the hours per diem during which they are run, making the broad distinction of 20 to 24 hour runs and 9 to 12 hour power, there are however two plants that, owing to wide difference of running time could not be brought under these headings, and they have therefore been placed by themselves in table VI.

TABLE II. POWER PLANT EQUIPMENT, ENGINES, VALUES AND LABOR.

No. of plant.	ENGINES.								VALUES.		LABOR.				Purposes for which steam is used other than for power, from same boilers, at same time.
	No. of Engines.	Type.	How Run.	Cylinders.			Rv'ls per min.	Rated H. P.	Total power plant.	Per rated H. P.	Engineers.		Firemen, etc		
				Diam high inches	Diam low inches	stroke inches					No.	Rate per mo.	No.	Rate per mo.	
1	1	Corliss	non-condensing	22	..	48	80	380	$14,865	$39.12	2	$78	2	$60	Exhaust heating, during winter.
2	1	Cummer.	condensing	22.1	..	42	78	250	11,000	44.00	2	78	2	45	
3	1	Corliss	non-condensing	16	..	36	86	125	18,300	89.27	1	125	2	48	Steam tables, elevator and other pumps.
	1	Slide Valve	used occasionally.	12	..	20	162	80			2	62	.	..	
4	1	Slide Valve	non-condensing	12	..	16	125	40	2,337	58.42	1	65	.	..	Steam tables; exhaust for building in winter.
	1	Compound Automatic	non condensing	8	14	14	194	65							
5	1	Vertical	non-condensing	16 7/16	..	20	74	65	1,500	23.08	1	90	.	..	Steam tables and neighboring building.
6	1	Vertical Compound	condensing	15	30	20	60	100	10,143	46.10	1	125	1	52	Steam tables; heating building in winter.
	1	Straight Line	non-condensing	10	..	16	235	60			2	65	1	40	Elevator and other pumps.
	1	Ball	non-condensing	10	..	12	275	60							
7	1	Corliss Compound	condensing	30⅜	56	60	68	1,500	100,000	40.00	1	100	4	55	
	1	Corliss Compound	condensing	26	42	48	75	1,000			2	75	4	50	
											2	50			
8	1	Wheelock	non-condensing	17	..	38	100	165	11,200	67.88	1	45	1	36	
9	2	Holly double Compound	condensing	36	72	48	16	....	632,000	287.90	1	167	9	61	
	1	Holly double Compound	condensing	33	66	48	16	...			3	87	2	40	
	2	Worthington Compound	condensing	38	66	50	10	....			7	40	6	40	
	1	Worthington Compound	condensing.	29	50	50	10	....			7	45			
10	2	Holly Compound	condensing.	12	24	22	21	....	40,478	367.98	1	100	2	45	
											1	75			
11	2	Holly Compound	condensing	12	24¼	22	19	....	28,000	254.54	1	100	2	48	Part of last year for electric power station in same building.
											1	50			
12	1	Slide Valve	non-condensing	25	..	36	78	300	9,500	31.66	1	78	1	45	For small electric light plant occasionally.
13	2	Compound Automatic,	non-condensing	8	13¾	12	235	65	7,730	46.85	1	100	1	43	For elevator and other pumps and to help exhaust in winter.
	1	Westinghouse	non-condensing	..	..	..	..	35			2	65			
14	1	Buckeye	non-condensing	12	..	22	140	65	4,500	69.23	1	75	1	48	For heating ovens and part of bnilding.
											1	56			
15	1	Slide Valve	non-condensing	12	..	12	250	80	3,000	37.50	1	48	.	..	To help exhaust in winter Exhaust used for dry rooms all the year
16	1	Wright	non-condensing	22¼	..	42	68	200	7,000	35.00	1	78	1	45	To help exhaust in winter. Exhaust used for dry rooms all the year
17	1	Corliss trip. comp.	condensing	24	1–34 2–36	60	62½	1,200	57,500	47.92	½	100	2	35	1st asst Eng. @ $32 and 1 coal wheeler @ $30
18	1	Corliss dbl. tand. comp.	condensing	22	40	60	68	1,000	71,434	71.43	1	75	2	35	One oiler @ $35 for slashers and vapor.
19	1	Corliss double	⅛ condensing	22	..	60	54	600			1	75	2	33	Exhaust from one cyl. of Nos. 1 & 2 for slashers
	1	Corliss double	½ condensing	22	..	60	64	600			1	100	2	32	Live steam for heating and vapor.
	1	Corliss cross comp.	condensing	24	44	60	68	800			1	50	1	42	
	1	Corliss cross comp.	condensing	22	40	60	65.8	500	146,550	56.75	2	42	3	36	Watchman @ $48.
20	1	Corliss cross comp	condensing	28	52	60	66¼	1,200			1	90	3	36	One coal wheeler at $30.
	1	Corliss double	¾ condensing	28	..	60	57	800	110,000	55.00	2	36	2	26	Exhaust form slashers and vapor.
21	1	Corliss cross comp	condensing	28	52	72	63	1,400	68,789	49.14	1	100	2	38	Two wheelers @ $33.
22	1	Corliss cross comp.	condensing.	23	52	72	57	1 200	64,000	55.33	1	67	1	40	One fireman @ $34, one wheeler @ $47, steam for vapor and slashers.

TABLE III.

ANNUAL OUTPUT AND COST PER HORSE-POWER.

	OUTPUT.						OPERATING EXPENSES.						FIXED CHARGES.					
No of plant.	Average H. P. develpd.	Per cent. of total engine capacity.	No. of days	Time per day.		Hours per annum.	Fuel.	Wages	Supplies.	Repairs	Water.	Total.	Interest.	Depreciation.	Insurance.	Taxes.	Total.	Cost per horse-power.
				hrs.	mins.													
1	296.7	78	297	24	..	7,128	$26.20	$10.95	$1.68	$5.77	$0.96	$45.56	$2.55	$3.52	$1.07	$0.67	$7.81	$53.37
2	210.9	85	290	24	..	6,960	22.00	13.26	3.94	1.13	....	40.33	2.61	2.80	1.50	95	7.86	48.19
3	58 8	47	365	24	..	8,135	36.30	44.60	9.90	3.60	2.90	97.30	13 87	12 24	2.61	5.10	33.82	131 12
4	12.4	31	361	9	..	3,067	48.93	84.12	9.13	1.62	4.13	147.93	9 46	11.62	1.89	2.43	25.40	173 33
5	21.5	33	361	9	..	3,711	28.82	51.09	7.34	1.24	1.98	90.47	8.13	6.98	1.94	.75	17.80	108 27
6	70.4	32	365	23	..	7,461	34.00	55.07	5.09	5.40	2 13	101.69	5.77	9.24	4.62	1.13	20.78	122.45
7	1,345.5	54	365	11	..	4,008	11.75	8.90	.55	2.01	.07	23 28	3.71	5.21	.26	.24	9.42	32 70
8	129.3	78	365	12	27	4,544	18 25	9.82	.58	.72	.77	30.14	2.97	5.28	1.16	....	9 41	39 55
9	1,352.	62	365	24	..	8,760	13.76	13.00	2 74	3.53	....	33.03	13.10	12.78	3.53	....	29.41	62 44
10	36 7	33	365	24	..	8,327	36.71	81.62	8.70	10.22	....	137.25	44.10	43.40	1.30	7.80	96 70	233.95
11	42.4	39	365	24	..	8,755	26.54	54.49	3.96	1.39	....	86.38	26.41	28.29	1.43	7.07	63.20	149 58
12	173.	58	313	3	..	939	11.98	8.53	1 05	.88	.22	2.66	3 40	3.22	1.46	.55	8.63	31 29
13	53.	32	309	15	30	4,790	24.43	25.50	2.35	1.93	2.73	56.94	7 29	9.57	1.19	1.46	19 51	76.45
14	20.9	32	365	24	..	8,110	49.30	55 30	8 83	3.59	6.10	123.12	10.79	13.33	2.15	2.15	28.42	151.54
15	32.9	41	330	10	20	3,410	9 58	8.74	2.92	1.22	.10	22.56	1.88	3.76	.19	....	5.83	28.39
16	166.7	84	313	9	50	3,073	5.46	7.48	1.36	.58	.31	15.19	1 57	2.02	.74	.14	4.47	19.66
17	1,174 8	98	306	9	40	2,958	7 62	1.82	.54	.21	....	10.19	2.30	2.35	.35	60	5.50	15.69
18	926.	93	307	9	40	2,963	8.64	2.20	.62	.27	....	11.73	3.68	3.93	.20	.96	8.77	20.50
19	2,422.	97	306	9	40	2,958	11.12	3.18	.81	.56	....	15.67	2.88	2.85	.25	.75	6.73	22 40
20	1,909.7	95	306	9	40	2,958	8.76	2.26	.82	1.56	....	13.40	2.62	3.21	.22	.58	6.63	20.03
21	1,278 7	91	293	9	40	2,831	7 40	2.41	.46	.22	....	10.49	2.57	2.96	.16	.54	6.23	16.72
22	1,010.86	84	306	9	40	2,958	8 89	2.24	1.35	3.22	....	15.70	3.04	3.36	.24	1.10	7.74	23.44

TABLE IIIA.

COST PER HORSE-POWER PER HOUR.

No. of Plant.	OPERATING EXPENSE.						FIXED CHARGES.					Cost per Horse Power
	Fuel.	Wages.	Supplies.	Repairs.	Water.	Total.	Interest.	Deprecia-tion.	Insurance.	Taxes.	Total.	
1	$ 00367	$.00154	$.00024	$.00081	$.00013	$.00640	$.00036	$ 00049	$.00015	$.00009	$.00109	$.00749
2	.00316	.00191	.00057	.00016	......	.00580	.00037	.00040	.00022	.00014	.00113	.00693
3	.00445	.00548	.00122	.00044	.00036	.01195	.00171	.00151	.00032	.00063	.00417	.01613
4	.01594	.02740	.00297	.00053	.00135	.04820	.00308	.00379	.00062	.00079	.00828	.05648
5	.00778	.01376	.00198	.00033	.00053	.02440	.00218	.00188	.00052	.00020	.00478	.02918
6	.00455	.00738	.00068	.00072	.00028	.01361	00077	.00124	.00062	.00015	.00278	.01641
7	.00296	.00222	.00014	.00051	.00002	.00585	.00092	.00131	.00006	.00006	.00235	.00820
8	.00402	.00216	.00013	.00016	.00017	.00664	.00065	.00116	.00026	......	.00207	.00871
9	.00157	.00148	.00031	.00040	......	.00377	.00149	.00146	.00040	......	.00336	.00713
10	.00441	.00981	.00104	.00123	......	.01650	.00530	.00522	.00015	.00094	.01161	.02811
11	.00303	.00622	.00045	.00016	......	.00986	.00302	.00323	.00016	.00081	.00722	.01708
12	.01276	.00910	.00112	.00094	.00023	.02415	.00362	.00343	.00155	.00058	.00918	.03333
13	.00511	.00532	.00049	.00040	.00057	.01190	.00152	.00199	.00025	.00030	.00406	.01596
14	.00608	.00683	.00109	00044	.00075	.01520	.00133	.00164	.00020	.00026	.00350	.01868
15	.00281	.00256	.00085	.00036	.00003	.00661	.00055	.00110	.00005	......	.00171	.00832
16	.00178	00244	.00044	.00018	.00011	.00494	.00051	.00065	.00024	.00005	.00145	.00639
17	.00258	.00062	.00018	.00007	......	.00345	.00078	.00079	.00008	.00021	.00186	.00531
18	.00292	.00074	.00021	.00009	......	.00396	.00124	.00133	.00006	.00032	.00295	.00691
19	.00377	.00107	.00027	.00019	......	.00530	.00098	.00096	.00008	.00025	.00227	.00757
20	.00296	.00076	.00028	.00053	......	.00453	.00089	.00109	.00007	.00019	.00224	.00677
21	.00261	.00085	.00016	.00008	......	.00370	.00091	.00104	.00005	.00020	.00220	.00590
22	.00301	.00076	.00046	.00109	......	.00532	.00103	.00114	.00008	.00037	.00262	.00794

In considering the plants under these general divisions, it must still be borne in mind that while they are classed under the same heading in hours per diem, they are by no means all run the same number of days per year, and therefore the total hours per annum during which the plant was run becomes the only correct basis on which to compute the cost for comparison.

In the above tables the unit costs per year, per day and per hour, have been computed and placed in parallel columns, the first and last being from table III, while the cost per day is deduced from the actual number of days run, divided into the cost per annum.

TABLE IV.

UNIT COSTS FOR 20 TO 24 HOUR POWER.

Number of Plant.	Average Horse-Power Developed.	COSTS. Per Horse-Power, Year.	Per Horse-Power, Day.	Per Horse-Power, Hour.
1	290.7	$53.37	$.1797	$.00749
2	210.9	48.19	.1602	.00693
3	58.8	131.12	.3592	.01613
6	70.4	122.45	.3355	.01641
9	1352.0	62.44	.1711	.00713
10	36.7	233.95	.6400	.02811
11	42.4	149.58	.4008	.01708
14	20.9	151.54	.4152	.01868

TABLE V.

UNIT COSTS FOR 9 TO 12 HOUR POWER.

Number of Plant.	Average Horse-Power Developed.	COSTS. Per Horse-Power, Year.	Per Horse-Power, Day.	Per Horse-Power, Hour.
4	12.4	$173.33	$.4801	$.05648
5	21.5	108.27	.3000	.02918
7	1345.5	32.70	.0896	.00820
8	129.3	38.55	.1084	.00871
15	32.9	28.39	.0860	.00832
16	166.7	19.66	.0628	.00639
17	1174.8	15.69	.0513	.00531
18	926.0	20.50	.0669	.00691
19	2422.0	22.40	.0732	.00757
20	1909.7	20.03	.0655	.00677
21	1278.7	16.72	.0571	.00590
22	1010.8	23.44	.0767	.00794

In tables VII, VIII and XI, and under the same general headings as to hours run per diem, as in tables IV, V and VI, a comparison is made of the amount of power used as compared with

TABLE VI.

UNIT COSTS FOR 3 HOUR POWER AND FOR 15½ HOUR POWER.

Hours Run.	Number of Plant.	Average Horse-Power Developed.	COSTS.		
			Per Horse-Power, Year.	Per Horse-Power, Day.	Per Horse-Power, Hour.
3	12	173	$31.29	$.1000	$.03333
15½	13	53	76.45	.2473	.01596

the actual rated capacity and under the items of expense are shown the total operating expense per hour, the total fixed charges per hour and in the last two columns the percentage each is of the total cost.

TABLE VII.

COMPARISON OF POWER AND EXPENSES.

20 TO 24 HOURS.

No. of Plant.	Rated Capacity, H. P.	Average Used H. P.	Per cent. Used of Capacity.	EXPENSE PER H. P. HOUR.			
				Operating.	Fixed.	Per cent. Operating of Total	Per cent. Fixed of Total.
1	380	296.7	78	$.00640	$.00109	85	15
2	250	210.9	85	.00580	.00113	84	16
3	205	58.8	47	.01195	.00417	74	26
6	220	70.4	32	.01361	.00278	83	17
9	2195	1352.0	62	.00377	.00336	53	47
10	110	36.7	33	.01650	.01161	58	42
11	110	42.4	39	.00986	.00722	57	43
14	65	20.9	32	.01520	.00356	81	19

TABLE VIII.

COMPARISON OF POWER AND EXPENSES.

9 HOURS TO 12 HOURS.

No. of Plant.	Rated Capacity, H. P.	Average Used H. P.	Per cent. Used of Capacity.	EXPENSE PER H. P. HOUR.			
				Operating.	Fixed.	Per cent. Operating of Total.	Per cent. Fixed of Total.
4	105	12.4	31	$.04820	$.00828	86	14
5	65	21.5	33	.02440	.00478	84	16
7	2500	1345.5	54	.00585	.00235	71	29
8	165	128.3	78	.00664	.00207	76	24
15	80	32.9	41	.00661	.00171	79	21
16	200	166.7	84	.00494	.00145	77	23
17	1200	1174.8	98	.00345	.00186	65	35
18	1000	926.0	93	.00396	.00295	57	43
19	2500	2422.0	97	.00530	.00227	71	29
20	2000	1909.7	95	.00453	.00224	67	33
21	1400	1278.7	91	.00370	.00220	63	37
22	1200	1010.8	84	.00532	.00262	67	33

TABLE IX.

COMPARISON OF POWER AND EXPENSES.

3 HOURS AND 15½ HOURS.

No. of Plant.	Hours Run.	Rated Capacity H. P.	Average Used H. P.	Per cent. Used of Capacity.	Expenses per H. P. Hour.			
					Operating.	Fixed.	Per cent. Operating of Total.	Per cent. Fixed of Total.
12	3	300	173	58	.02415	.00918	72	28
13	15½	165	53	32	.01190	.00406	75	25

Referring back to table IV and taking up the plants in order, it will be well to discuss each one, in-so-far as may be necessary to explain why it differs in cost from another similar plant of which test is also given.

Commencing then with plants No. 1 and 2, being used for similar purposes, the first being somewhat larger in capacity than the second.

The first has a Corliss, non-condensing engine and boilers of a very efficient vertical type, while the second has old and comparatively inefficient return tubular boilers, but a good type of engine, running condensing, which accounts for the cost being somewhat less than for plant number one.

It may be said that during the test the first of these plants was found to be using a great deal more coal when the night fireman was on duty, than the day fireman used in the same length of time, and for an average of two horse-power in excess over that developed during the night. Since the test, this has been remedied and it is said that the plant is now running at a very considerable saving over its former condition. The waste of coal as mentioned above, is one of the items that cannot be included in any theoretical computation, but is too common in practice.

Plants 3 and 6, both run similar types of business, the first getting its power from a fine simple Corliss engine kept in the best of order, while the other uses one very old type of engine running compound condensing, and two small high speed engines, running at high pressure. Both plants are well kept and the final results in costs per horse-power per hour is seen to vary but .0003.

The next three cases 9, 10, 11 are three pumping stations under city control, and while the total cost seems high, it must be remembered that fixed charges account for a good part of the entire expense, and in making comparisons between plants of this kind and other power, it will be more fair to compare operating expenses only, and in that case the showing while high is not so much higher than for other plants of a similar capacity as to be startling.

The last case in this division, No. 14, was the only one of the nature of business carried on and the only detail given will be to say that it had a Buckeye engine, kept in the best of order.

Plants Nos. 4 and 5, in table v, are used in similar business, and in spite of the fact that the first has by far the better plant, the cost is seen to be a great deal higher than in the second case, and mainly for the reason that a larger average output is obtained from the latter plant.

Case No. 7 in the same table is one in which the circumstances were such as to enable the determination of cost with extreme accuracy, the output being uniform and constant and the accounts most accurately kept. The cost is somewhat higher than it might be, owing to rather low ratio of output to capacity, but this has since been remedied and the unit cost materially reduced.

Plant No. 8 is one that will answer for a type of hundreds of small electric lighting stations in the United States, and the test is only remarkable in the variety of output, making it necessary to do a very large amount of calculation in order to arrive at anything like reasonably correct results. Fortunately for the purpose, ampere records had been kept of the incandescent part of the output, as well as a clear record of the number of arc lamps run, together with the time of running for each night of the year.

By making an indicator test of the engine, and at the same time recording the amperes and volts at the switchboard, it was easy to arrive at the average power for a complete run and thus to establish a ratio of steam power to electrical output for the entire year, and by means of the ratio converting it into horse-power, an average power for the entire year was determined.

The resulting cost per horse-power is surprisingly low and is due to several things, first, low rate of wages; second, just as little labor as could run the plant, and third, cheap fuel.

A calculation of the cost of the electric output in this plant shows it to be not nearly so economical as might with reason be expected from the low cost of steam power, and is due to the low average efficiency of the plant, caused by running for many hours at light loads.

Plant No. 15, is one of that type of plants that uses steam for power purposes, more as an incident of the manufacture than as one of the prime factors in cost.

Steam for drying goods is the chief factor in plants of this kind, and in this case all the exhaust from the engine and in cold weather much live steam is used for drying purposes.

Plant No. 16, like the last one, uses a great proportion of its steam for drying purposes, and an additional factor for low power cost is, that nearly all fuel for day use is the waste wood and shavings from the manufacture. Add to this the fact that the machinist acts as engineer, and the engine is of good size and located in the machine repair shops and it will be seen that most of the factors in the case make a very low cost of power.

Plants Nos. 17 to 22 inclusive, are large cotton mills, in an eastern state. The statement made in the early part of this paper, seems to be borne out that, while it might be thought that mills of this nature using as large units of power as do these, and in a business so near alike for all, would perhaps show a more uniform cost of power, still vary a somewhat larger amount than would be practicable to average.

The cost of the lowest, No. 17, is $00531 per horse-power hour and the highest, No. 22, $00794, a difference of nearly 50 per cent increase over the first mentioned plant. To be sure, the first named plant (No. 17) is a new style Corliss, 4 cylinder, triple expansion, condensing engine, while the last (No. 22) is of the cross-compound condensing Corliss type.

Of course, it is readily seen that the extra cost could not be in fuel efficiency, and by reference to table III, it will be seen that the difference is in "supplies" and "repairs" to a very large extent, caused by a charge of part of the expense of replacing the whole bank of boilers. This is one of the items of cost that so often happen in steam plants, and the charge is seldom included in figuring the cost of power.

Comparing No. 17 with No. 21, the total cost per hour for the former is $.00531 and for the latter $.0059, a difference of $.00059, or 11 per cent of the first named plant.

Again referring to table III, another perhaps unexpected result is found, *i. e.* the fuel cost for the triple expansion engine is higher than in the other (No. 21), which is a Corliss cross-compound condensing engine.

As both plants use Manning boilers that are presumably of like efficiency, a reference to table I shows that the coal used in No. 17 cost $3.35 per ton, while the mixture used in No. 21, cost but $2.57 and the difference in quantity used that may have been due to higher engine economy, seems not to have made up for the difference in price.

Taking up the wages cost for these six plants, an examination of tables III and III a, shows a very considerable variation in that item, due to a number of different factors: for instance, No. 22 has but one engineer, with not even an oiler, but the number of firemen used brings up the cost to a trifle more than on No. 17, where the one engineer divides his time equally between the plant examined and another one, and therefore equally divides the cost, an oiler looking directly after the care of the engine; and the divisor (amount of power developed) is greater in the first case, thus materially reducing the unit cost. The labor cost in steam power can be made one of the greatest variables in it and when it is found to be a fact that one engineer at say $3.00 per day, can and does successfully run an engine developing over a thousand horse-power, and yet no less cost than this is required for running a plant of say 200 or even 100 horse-power, it is readily seen that the unit cost differs materially in the two cases and will vary proportionally between the two limits. Of course this is not advanced as new in theory but the writer wishes to call rather closer attention to the point than seems to have been given it in the past.

In table VI, the first plant No. 12, is a large grain elevator in which power is used spasmodically and averages but 3 hours out of the 24 the year round. This power varies in amount to a great extent, running at times as low as 43 horse-power and again with the "marine leg" on, and other "lofters" as high as 250 horse-power may be in use for a short time. The average 173 horse-power is somewhat higher than might be expected with the entire disuse of the marine leg in winter, and only the inside legs going during that time, but it checks well with all the tests made on the plant.

Plant No. 13 is run for 15½ hours every working day of the year and in spite of the fact that the engine and dynamo plant is in duplicate, the cost per horse-power is quite low; this is mainly due to extremely good management and careful accounting. Power is mainly used for running electric lights and one or two small motors. Steam is used for power and for an elevator and other pumps. An accurate record is kept of the weight of coal used each day, and the reading of the ampere and voltmeters is registered all day long at hourly intervals, thus enabling a quite accurate estimate to be made of the average power, by determining the ratio of cylinder power to ampere readings.

While the above 22 plants are the only ones on which tests available for this paper were carried out, many others were examined during the time, and while it may be said that in most plants fairly accurate tests may be made, some are found in which it is next to impossible to arrive at anything like accurate results.

Until one makes a business of examining power plants with an idea of learning the unit cost of power, it is impossible to judge adequately of the varying conditions obtaining and therefore of the fact that any possible statement of an average cost is misleading.

It has been the writer's experience that one of the greatest factors for varying the cost of steam power in a given plant is to be found in the fire room.

In but few plants is this part of the expense found to receive the attention it should have to obtain the best results; and as a whole, the men employed at the work of firing are of a class that seldom runs to brains, and unless pushed to it by the management, the engineer is prone to exercise only a nominal supervision over the department. When a fireman on one shift can use nearly twice as much coal doing the same work as the fireman on the other shift as was found in one case, it is time the engineer was disposed of or new methods arranged.

In plants developing a low amount of power, say less than 100 horse-power, as a large majority of them do, the labor item due to varying conditions of the business, becomes a very important factor, and one in which great saving can be made by re-arrangement of power supply.

In order to make this paper of greater value, the writer has thought it well to add the results of estimates by other investigators and, as coal is the only item that varies to a great extent in unit price, it has been thought best to bring that item to the same price per ton, and, as the ton used in the neighborhood where most of the tests were made is 2,000 pounds, all weights and prices have been reduced to a cost of $3.00 per 2,000 pounds, delivered.

Tables x to xvii inclusive, are the results of the tests by the writer, classified by types of plant, and reduced to coal at $3.00 per 2,000 pounds. These tables show the number of the plant as given in the previous tables, the hours run per diem, the average power developed, operating, fixed and total expense per hour per horse-power.

Table x, shows the costs for slow speed non-condensing engines, irrespective of the size or number of hours run per diem. Although an average is taken of these, it is of course of little value as the costs vary not only by reason of the amount of power developed but from the number of hours run per diem, and the variety of each of these conditions is such that each item could as well be placed by itself.

Table xi shows results for high speed automatic engines, which are also assembled irrespective of time of running or power developed and show very uneven costs.

Tables xii and xiii include but one plant each, and are therefore of little use for comparison, excepting as showning the general variation of cost.

TABLE X.

Coal Reduced to $3.00 per 2,000 Lbs.

Slow Speed. Non-Condensing.

Number of Plant.	Hours Run.	Average Power.	EXPENSES.		
			Operating.	Fixed.	Total.
1	24	296.7	$.00821	$.00109	$.00930
3	23	58.8	01343	.00417	.01760
5	9	21.5	.02865	.00478	.03343
8	12	129.3	.00692	.00207	.00899
16	10	166.7	.00591	.00145	.00736
12	3	173.	.02789	.00918	.03707
Averages..	....	....	$.01517	$.00379	$.01896

TABLE XI.

COAL REDUCED TO $3.00 PER 2,000 LBS.
HIGH SPEED. AUTOMATIC NON-CONDENSING.

Number of Plant.	Hours Run.	Average Power.	EXPENSES.		
			Operating.	Fixed.	Total.
14	24	20.9	$.01802	$.00350	$.02152
4	9	12.4	.05686	.00828	.06514
15	10	32.0	.00824	.00171	.00995
13	15	53	.01446	.00406	.01852
Averages..	.. ....	....	$.02430	$.00439	$.02878

TABLE XII.

COAL REDUCED TO $3.00 PER 2,000 LBS.
SLOW SPEED CONDENSING.

Number of Plant.	Hours Run.	Average Power.	EXPENSES.		
			Operating.	Fixed.	Total.
2	24	210.9	$.00785	$.00113	$.00898

TABLE XIII.

COAL REDUCED TO $3.00 PER 2,000 LBS.
COMBINED. COMPOUND-CONDENSING AND AUTOMATIC NON-CONDENSING.

Number of Plant.	Hours Run.	Average Power.	EXPENSES.		
			Operating.	Fixed.	Total.
6	23	70.4	$.01573	$.00273	$ 01851

Table XIV, shows like results for three pumping stations, and one gets a very good idea of the vast difference in unit cost of power when developed is widely varying quantities; the first plant, developing 1,352 horse-power, and the other two less than 50 horse-power each, the difference in cost between the highest and the lowest being as $.007 is to $.03048.

TABLE XIV.

COAL REDUCED TO $3.00 PER 2,000 LBS.
PUMPING ENGINES, COMPOUND CONDENSING.

Number of Plant.	Hours Run.	Average Power.	EXPENSES.		
			Operating	Fixed.	Total.
9	24	1352.	$.00455	$.00336	$.00791
10	24	36.7	.01887	.01161	.03048
11	24	42.4	.01149	.00722	.01871
Averages..	....	....	.01174	.00739	.01913

In table XV, is shown the cost for four large plants using slow speed compound condensing engines. This type of plant is perhaps the most common of modern plants in use for large quantities of power, and is one on which perhaps the most and best estimates have been made, and therefore most easily compared with other tables.

TABLE XV.

COAL REDUCED TO $3.00 PER 2,000 LBS.
SLOW SPEED COMPOUND CONDENSING.

Number of Plant.	Hours Run.	Average Power	EXPENSES.		
			Operating.	Fixed.	Total.
7	11	1345.5	$.00901	$.00235	$.01136
18	10	926.0	.00447	.00295	.00742
21	10	1278.7	.00414	.00220	.00634
22	10	1010.8	.00522	.00262	.00784
Averages..	....	....	.00571	.00253	.00824

Table XVI, shows the result in one plant using a large triple compound engine of special type, and one of the items tending to low cost in this instance, is that but half the engineer's time is chargeable to this particular plant; another being the low fixed charge owing to very close buying by the management. The cost of power here will be seen to be less than generally estimated.

TABLE XVI.

COAL REDUCED TO $3.00 PER 2,000 LBS.

SLOW SPEED TRIPLE COMPOUND CONDENSING.

Number of Plant.	Hours Run.	Average Power.	EXPENSES.		
			Operating.	Fixed.	Total.
17	10	1174.8	$.00318	$.00186	$.00504

Table XVII, shows the results in two mixed plants of large size, both cotton mills. In both cases about half the plant consists of the best type of compound condensing engines, while the remainder is made up of the old-fashioned double Corliss part condensing type, the exhaust from one end of each cylinder being generally used for purposes of heating about the mills. In passing, it may be well to say that most of the modern cotton mill plants use steam for heating direct from the boiler through pressure reducing valves, and not from any part of the exhaust of the engines.

TABLE XVII.

COAL REDUCED TO $3.00 PER 2,000 LBS.

COMBINED, COMPOUND CONDENSING AND SIMPLE CONDENSING.

Number of Plant.	Hours Run.	Average Power.	EXPENSES.		
			Operating.	Fixed.	Total.
19	10	2422.	$.00460	$.00227	$.00687
20	10	1909.7	.00527	.00224	.00751
Averages..	....	....	$.00404	$.00225	$.00719

COMPARISONS.

Of modern investigations of the cost of power, none stand higher than those of Dr. C. E. Emery in a paper before the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, March 21st, 1893, I have therefore thought it well to include here such parts of the tables as will afford a chance for comparison with the work of the writer and that of others. The investigation by Dr. Emery in this particular case was confined to the large unit of 500 net horse-power and its application must be limited to that amount as any departure will be found to vary the results.

KEY TO TABLES XVIII, XIX, XX AND XXI.

Style of Engine.	
A.	Simple High Speed Non-Condensing.
B.	Simple Low Speed Non-Condensing.
C.	Compound High Speed Non-Condensing.
D.	Special Triple Compound High Speed Non-Condensing.
E.	Simple High Speed Condensing.
F.	Simple Low Speed Condensing.
G.	Compound High Speed Condensing.
H.	Compound Low Speed Condensing.
I.	Special Triple Compound High Speed Condensing.
J.	Triple Compound, Low Speed Condensing.
K.	Triple Compound, Low Speed Condensing.
L.	Ditto, for probable maximum results.

As Dr. Emery's computations are made on net power and with coal at 2,240 pounds per ton, it has been necessary to reduce his figures to indicated horse-power and coal at 2,000 pounds per ton, the results being found in tables XVIII and XIX following. Where necessary to bring the items of expense under the same heads, changes have been made in his tables so that direct comparison of items may be made.

Table XVIII shows itemized costs for 10 hour power per annum and in tables XX and XXI the totals have been reduced to cost

TABLE XVIII.

EMERY'S TABLES REDUCED TO INDICATED HORSE-POWER AND COAL AT $3.00 PER 2,000 LBS. 3,080 HOURS RUN.

Style of Engine.	OPERATING EXPENSE.				FIXED CHARGES		Total.	Total Cost.
	Coal.	Labor.	Repairs and Supplies.	Total.	Insurance, Taxes & Renewals	Interest.		
A	$19.70	$4.41	$2.73	$26.84	$2.72	$5.90	$8.62	$35.46
B	17.34	4.04	2.28	23.66	2.82	6.13	8.95	32.61
C	15.54	3.84	2.73	22.11	2.52	5.49	8.01	30.12
D	14.35	3.68	2.73	20.76	2.78	6.03	8.81	29.57
E	13.15	3.51	2.73	19.39	2.32	5.04	7.36	26.75
F	11.94	3.31	2.28	17.53	2.46	5.35	7.81	25.34
G	11.05	3.35	2.73	18.03	2.39	5.16	7.57	25.60
H	10.76	3.14	2.28	16.18	2.50	5.43	7.93	24.11
I	10.15	3.10	2.73	15.98	2.53	5.49	8.02	24.00
J	9.56	2.98	2.28	14.82	2.82	6.11	8.93	23.75
K	8.96	2.90	2.28	14.14	3.02	6.56	9.58	23.72
L	7.50	3.36	2.28	13.14	2.98	6.45	9.43	22.57

per hour per horse-power in order to conform with the argument of the writer that the only correct safe statement is cost per hour and not per annum.

TABLE XIX.

EMERY'S TABLES REDUCED TO INDICATED HORSE-POWER AND COAL AT $3.00 PER 2,000 LBS. 7,300 HOURS RUN.

Style of Engine.	OPERATING EXPENSE.				FIXED CHARGES		Total.	Total Cost.
	Coal.	Labor.	Repairs and Supplies.	Total.	Insurance. Taxes & Renewals.	Interest.		
A	$44.70	$10.45	$6.47	$61.62	$2.72	$5.90	$8.62	$70.24
B	39.20	9.57	5.38	54.15	2.83	6.13	8.96	63.11
C	35.20	9.11	6.47	50.78	2.53	5.49	8.02	58.80
D	32.50	8.72	6.47	47.69	2.78	6.02	8.80	56.49
E	29.70	8.34	6.47	44.51	2.32	$5.04	7.36	51.87
F	27.10	7.84	5.38	40.32	2.46	5.35	7.81	48.13
G	27.10	7.93	6.47	41.50	2.39	5.17	7.56	49.06
H	24.30	7.45	5.38	37.13	2.50	5.44	7.94	45.07
I	22.90	7.35	6.47	36.72	2.53	$5.49	8.02	44.74
J	21.64	7.07	5.38	34.09	2.81	6.14	8.95	43.04
K	20.30	6.85	5.38	32.53	3.02	6.57	9.59	42.12
L	16.93	7.98	5.38	30.29	2.98	6.44	9.42	39.71

TABLE XX.

COST PER HORSE POWER HOUR, FROM EMERY'S TABLES. 3,080 HOURS RUN.

Style of Engine.	Operating Expenses.	Fixed Charges.	Total Cost.
A	$.00870	$.00280	$.01150
B	.00700	.00291	.01060
C	.00710	.00261	.00980
D	.00675	.00286	.00961
E	.00630	.00239	.00869
F	.00570	.00254	.00824
G	.00587	.00246	.00833
H	.00526	.00258	.00784
I	.00520	.00261	.00781
J	.00482	.00290	.00772
K	.00460	.00311	.00771
L	.00428	.00307	.00735

In a discussion of a paper before the American Society of Mechanical Engineers, Mr. Samuel Webber took occasion to state the itemized cost of steam power as developed in a Fall River yarn mill and the results are here given in tables XXIII and XXIV with coal reduced to $3.00 per 2,000 pounds.

The totals will be found to agree fairly well with those from

TABLE XXI.

COST PER HORSE-POWER, HOUR, FROM EMERY'S TABLES. 7,300 HOURS RUN.

Style of Engine.	Operating Expenses.	Fixed Charges.	Total Cost.
A	.00845	.00122	.00967
B	.00741	.00123	00864
C	.00695	.00110	.00805
D	.00652	.00121	.00773
E	.00610	.00101	.00711
F	.00551	.00107	.00658
G	.00568	.00103	.00671
H	.00508	.00109	.00617
I	.00502	.00110	.00612
J	.00466	.00123	.00589
K	.00445	.00131	.00576
L	.00414	.00129	.00543

COST OF POWER, FROM TABLE IN ENGINEERING MAGAZINE, BY DR. EMERY. COAL REDUCED TO $3.00 PER 2,000 POUNDS. 3,080 HOURS.

	Net Horse-Power.	Cost per H. P. per Hour.
Ordinary non-condensing	10	$.02570
Automatic Cut-off, non-condensing	75	.01396
Automatie Cut-off, condensing	150	.01060
Compound Condensing	250	.00856
Triple Compound Condensing	500	.00727

TABLE XXIII.

COST OF POWER IN A FALL RIVER YARN MILL. SAMUEL WEBBER. COAL REDUCED TO $3.00 PER 2,000 LBS.

	Cost per H. P. per annum.	Cost per H. P. per hour.
OPERATING EXPENSES.		
Fuel	$9.20	$.00299
Wages	2.23	.00072
Repairs	1.57	.00051
Supplies	.31	.00010
Total	$13.31	$.00432
FIXED CHARGES.		
Interest, 5 per cent	$3.15	$.00102
Depreciation. 5 per cent	3.15	.00102
Insurance, non charged.	....	....
Taxes, 1 per cent	.32	.00010
Total	$6.62	$.00214
	$19 93	$.00646

similar plants, although no insurance has been taken into account; if $.00007 be added, the result will give a direct comparison with other estimates.

TABLE XXIV.

COST OF POWER IN GLOBE YARN MILLS, NO. 3. FALL RIVER. COAL REDUCED TO $3.00 PER 2,000 LBS. SAMUEL WEBER.

	Cost per H. P. per annum.	Cost per H. P. per hour.
OPERATING EXPENSE.		
Fuel	$10 73	$.00349
Wages	2.89	.00094
Repairs	1.62	.00053
Supplies	.40	.00013
Total	$15.64	$.00509
FIXED CHARGES.		
Interest, 5 per cent	$3.23	$.00105
Depreciation, 5 per cent	3.23	.00105
Insurance none, charged	....	......
Taxes 1 per cent	.22	$.00011
Total	$6.78	$.00221
	$22.42	$.00720

Table xxv, gives the result of a test made by Mr. R. S. Hale, expert for the Steam Users Association of Boston. Although

TABLE XXV.

COST OF POWER IN A LARGE COTTON MILL. R. S. HALE, BOSTON. COAL REDUCED TO $3.00 PER 2,000 LBS.

	Cost per H. P. per annum.	Cost per H. P. per hour.
OPERATING EXPENSES.		
Fuel	$6.92	$.00233
Wages	2.51	.00084
Repairs	.50	.00017
Supplies	.45	.00015
Total	$10.38	$.00340
FIXED CHARGES.		
Interest	$2.90	$.00097
Depreciation	2.40	.00081
Insurance	.22	.00007
Taxes	.69	.00023
Total	$6.21	$.00208
	$16.59	$.00557

developed to a most interesting degree, the cost of steam power for various costs of coal and where the exhaust from engines is used in varying quantities. He has divided the engines into three types or classes, *i. e.*, compound, condensing and high pressure, which are the three types most used in his locality, which is largely a centre for the manufacture of textiles. He has also stated the costs for engines of 500, 1,000, 1,500 and 2,000 horse-power capacity for each type and the results are very interesting, but too elaborate to be included in full in this paper.

I have, however, in tables XXVII and XXVIII assembled the unit costs for the various items, reducing the item of coal to the standard, for an engine of 1,000 horse-power of the three types, and with no exhaust steam used; in the first table, for the year, and in the second, per hour; the results will be found to agree fairly well with others.

TABLE XXIX.

COMPARISON OF DIFFERENT ESTIMATES.

LARGE, COMPOUND CONDENSING ENGINES.

	Cost per H. P. per Hour.
Emery, A. I. E. E., for 3,080 hours, table XX	$.00784
Emery, A. I. E. E.. for 7,090 hours, table XXI	.00617
Emery, *Eng. Magazine*, 3.080 hours	.00856
Webber, 650 H. P., 3,080 hours. table XXIV	.00720
Webber, 1,050 H. P., 3,080 hours, table XXIII	.00646
Hale, 2,985 hours, table XXV	.00557
Main, 3,080 hours, table XXVIII	.00637
Foster, average, 3,080 hours, table XV	.00824
Average of all	$.00705

CONCLUSIONS.

The writer has attempted in various ways, to group the foregoing tables for comparison with each other, but gave up the attempt as hopeless, with the exception of the class of large compound condensing engines used so generally in the large mills of the east; table XXIX shows the comparison of costs per hour as developed in the various tables in this class of engine, and although as previously stated by the writer, the average is hardly to be depended on for use in careful estimates, an average has been computed of the costs by different estimaters and is seen to be $.00705 per horse-power per hour. The especial point the writer desires to bring out, is the widely varying costs here shown; take for instance Mr. Hale's of $.00557 as compared

TABLE XXX.

COMPARISON OF COST OF POWER PER ANNUM.
BY VARIOUS TYPES OF ENGINES. COAL AT $3.00 PER 2,000 LBS.

Type of Engine and Number of Plant.	Power Developed.	Cost per H. P. per Annum.			
		Operating Expense.	Fixed Charge.	3,080 Hours	8 750 Hours.
Slow Speed Non-Condensing.................. 1	297	$71.92	$7.81	....	$79 73
" " " 3	59	117.55	33.82	....	151.37
" " " 5	22	88 24	17.80	106.04	....
" " " 8	129	21.31	9.41	30.72	....
" " " 16	187	18.20	4.47	22.67	....
" " " 12	173	85.90	8.63	94.53	....
" " " Emery........... B	556	23.66	8.95	32.61	....
" " " " .... B	556	64.91	8.06	....	73 87
" " " Main......XXVIII.	1,000	19.37	6.49	25.86	....
High Speed Non-Condensing.................. 14	21	157.86	28.42	....	186 28
" " " 4	12	175.13	25.40	200.53	....
" " " 15	33	25.38	5.83	31.21	....
" " " 13	53	44.54	19.51	64.05	....
" " " Emery Eng. Mag....	10	73.15	6.00	79.16	....
" " " " " " ...	75	36.50	6 50	43.00	....
" " " " " " ...	542	26.84	8.62	35.46	....
" " " " " " ...	542	74 02	8.82	....	82 64
Combination, Slow Comp. Cond. High Speed Non-Cond.......................... 6	70	137.79	20.76	....	158.55
Combination, Slow Speed Comp. Cond. and Dbl. Cond.......................... } 19	2,422	14.17	6.73	20.90	....
} 20	1,910	16.33	6.63	22.96	....
Compound High Speed Non-Cond. Emery.... C	542	22.11	8 01	30.12	....
" " " " " C	542	60.88	8.02	....	68 90
Compound High Speed Condensing. Emery.. G	542	18.03	7.57	25.60	....
" " " " " .. G	542	49.76	7.56	....	57.32
Triple Comp. High Speed Non-Cond. Emery. D	542	20.73	8.81	29.57	....
" " " " " " D	542	57.12	8.80	....	65.92
Triple Comp. High Speed Condensing. " I	542	15 93	8.02	24.00	....
" " " " " " I	542	43.98	8.02	....	52.00
Slow Speed Condensing......................... 2	211	68.87	7.83	....	76.75
" " " Emery.................. F	556	17 53	7.81	25.34	....
" " " " .... F	556	48.27	7.81	....	56 08
" " " " Main.....XXVIII.	1,000	16.82	6.36	23.18	....
High Speed Condensing. Emery .... E	542	19.33	7.36	26.75	....
" " " " .... E	542	53.44	7.36	....	60.80
" " " " Eng. Mag.......	150	26.65	6.00	32.65	....
Slow Speed Compound Condensing............ 7	1,346	27.75	9.42	37.17	....
" " " " 18	926	13.77	8.77	22.54	....
" " " " 21	1 279	12 75	6.23	18.98	....
" " " " 22	1 011	16.08	7.74	23.82	....
" " " " Emery..... H	556	16.18	7 93	24.11	....
" " " " " ..... H	556	44.50	7.94	....	52.44
" " " " Emery Eng. Mag...	250	19.96	6.40	26.36	....
" " " " Webber....XXIII.	1,050	13.31	6.62	19 93	....
" " " " " .....XXIV.	650	15.68	6 78	22 46	....
" " " " Hale.........XXV.	....	10.75	6 21	16.96	....
" " " " Main.....XXVIII.	1,000	13.40	6.36	19.76	....
Slow Speed Triple Comp. Condensing.......... 17	1,175	9.73	5.50	15.29	....
" " " " " Emery........ J	556	14.82	8.93	23.75	....
" " " " " " .... J	556	40.82	8.95	....	49.77
" " " " " " L	556	13.14	9.43	22.57	....
" " " " " " L	556	36.27	9 42	....	45.69
" " " " " " Eng. Mag ..	500	15.19	7.20	22.39	....
Water Works Pumps, Compound Cond........ 9	1,352	39.86	29.41	....	69.27
" " " " " 10	37	165.30	96.70	....	261.00
" " " " " 11	42	100.65	63 20	....	163 85
" " " Triple " " XXVI	560	47 30	11.64	....	58.94

with Dr. Emery's of $.00856 or the writer's of $.00824, the two last are seen to exceed the first by about 50 per cent, a variation which the writer argues does not permit of stating average costs for general use. And finally, in order that the report may be of more practical value, the results have in table xxx been assembled and reduced to cost per horse-power per annum, for ten hours per day for 308 days, and for 24 hours per day for 365 days.

The first column gives the type of engines, with the number of the plant from the tables; next the amount of power developed, as showing the size of the plant; then operating and fixed expense; and in the last two columns, the total cost per annum for 3,080 hours and 8,760 hours.

This table allows a direct comparison of different plants, and different authorities.

DISCUSSION.

THE PRESIDENT:—This subject is one upon which we are very dependent, and it is as Mr. Foster says, one that you can get all sorts of figures for. They are chiefly based upon what people think they are doing, and the paper is particularly valuable as being intended to give the facts as they actually are. In my own experience, I have heard of cases where power was supposed to be generated at a very low figure, but as a matter of fact, it was costing a great deal. Mr. Foster has devoted considerable time as well as intelligent effort to reaching the real results. The paper is open for discussion.

DR. PERRINE:—I would like to further emphasize one fact, to which Mr. Foster calls attention and to which he apparently attaches a good deal of importance, namely, that of the results of the plant No. 17. In spite of the fact that it was one of the best equipped plants mechanically, and used expensive coal, the cost of horse power was but little less than obtained with another plant using a poorer quality of coal; and in this is involved a question of the method of testing fuel in order to arrive at a definite conclusion as to what coal should be used in any particular plant. At one time—and I think it still exists somewhat—there was a tendency to throw doubt on the value of calorimeter tests of coals. The mechanical engineers as a rule say that this is not the best test of coal, but that the best test of any particular coal is by firing under the boilers, and seeing what result can be obtained. That is, of course, nothing more than the arriving at the result that the fireman can handle a particular coal better than he can handle another coal, but that does not say at all whether better economy might not be obtained by discharging that fireman and getting a new man, or by introducing mechanical stokers, or some means of using a different quality of coal.

As regards the question of the heat units contained in a pound of coal, I think there is far less difference between the poorest coals ordinarily in the market and the best coals. This I know was brought out in a paper, I think before the British Institution of Electrical Engineers—at any rate, before one of the British societies, on the cost of steam power. I cannot recall at the present time the date of the paper or even the author, but I remember that in the discussion, in which engineers had given the cost of operating a number of different electric plants, one engineer gave an example of his own plant in which he was using a cheap grade of coal, and by which he claimed that he was obtaining very high efficiency. The statement was made that he was using a particular quality of slack, giving not more than about 9,000 heat units per pound of coal, and as it was about one-half the best that can be obtained, there was quite a margin of loss of efficiency, which might be accounted for by the coal. He had not made any calorimeter tests, but arrived at this value of the heat units in the method that a great many engineers had arrived at it, by guesswork. It happened that the particular quality of coal used by this engineer had been tested by the author of the paper, and in place of being low in heat units, it was reasonably high. Instead of being 9,000 heat units, it was 13 to 14,000, and in place of the plant being economical on the basis of the coal used, it was not economical on the basis of the coal used; and this shows the effect of that class of rough and ready tests. Most of our economy of electrical machinery has been reached through the fact that electrical engineers are not content with guessing or assuming the efficiency of their plants, but actual tests of efficiency are made of a scientific character, and when these results are obtained, electricians have sufficient faith in their results to rely upon them, and the introduction of this same scientific spirit into the question of coal handling is one that has done a great deal in this country towards decreasing the cost of steam power, and as the methods of the scientist are extended, it will do a great deal more. The fact is, in the neighborhood of Chicago most of the mechanical engineers have finally ascertained that of the coals they can get there, the lowest priced coal is in general the coal which gives the cheapest steam power. But that does not say that in any particular plant the lowest price coal necessarily gives the cheapest steam power, because if we have a plant designed for anthracite coal, we cannot economically burn bituminous slack on the grate bars; but if at any particular locality bituminous slack is the cheapest coal to buy, then the most economical plant, as a rule, will be the plant which is built and adapted for that low priced coal. While Mr. Foster does not insist on this fact particularly, nevertheless his experiments with this plant No. 17 show that the choice of coal gives a tremendous basis for a change in the price of the steam power. In this particular plant, No. 17, a cheaper coal might give a lower efficiency, but, nevertheless, had the same care been used in designing the furnaces as was apparently used in the rest of the plant, it seems from the results of neighboring plants that a lower steam cost would have been obtained by the use of a cheaper coal, for otherwise there is apparently no result from the care with which the general machinery of the plant has been chosen. In all of this I mean to insist that we are necessarily to apply and rely upon the scientific methods of tests in every part of a plant in which we use our electrical machinery, and the rough and ready test of the every day mechanic is no more to be relied upon in the choice of fuel than it would be relied upon in the choice of a dynamo machine.

The Secretary:—One of the interesting facts in connection with the great development of steam power is that of the changes in prices of coal and the quantities of each size brought to market, due to the demand that has grown up for smaller sizes through their coming into use gradually on account of their cheapness. Perhaps a case that will be known to most of you is that of the difference between ordinary stove coal and chestnut coal. Chestnut coal was formerly cheaper at retail than stove coal, but in use it was found that for many reasons chestnut was more desirable, and so gradually the price was raised until the retail price of chestnut is now the same as that of stove coal. Then again, there has been a lot of coal piled up in culm heaps that formerly was considered good for nothing. Pea coal was brought into market in 1867, and in 1876 buckwheat coal was introduced. There is also rice coal, although the latter is used for fuel only at the mines, and that coal has recently had a market price of its own; whereas, years ago it could not be given away. We all know that there are certain goods and valuables that bear transportation better than others, and on account of high freights I would like to ask Dr. Perrine, about the kind of coal that is used in California. We know that they use a certain amount of anthracite. That has to be brought from long distances and we can all well understand that there are certain grades of coal which it is economical to use only near the mines, and where there is no cost for transportation. But if you have to carry that coal a great way, of course the freight on it is as much as it would be on a better class of coal. Consequently, it appears to me that the practice in different localities would show that it is only the best coal that can be transported and used economically.

As a matter of record it might be well to quote here a table prepared by Wm. McClave, of Scranton, and included in a paper read by him at Philadelphia, January 9th, 1895, before the "Anthracite Coal Operators Association." He takes the best bituminous or anthracite as a standard.

TABLE OF RELATIVE VALUES BY PERCENTAGE.

			To equal Anth. Egg, add to each ton.
Bituminous	Coal, good quality,	100%	
"	Slack, "	90%	11 1%
Anthracite	Steamboat, "	95%	5.3%
"	Broken, "	97%	3.1%
"	Egg, "	100%	
"	Stove, "	100%	
"	Chestnut, "	100%	
"	Pea, well cleaned and of good quality	95%	5.3%
"	Pea, mixed with bone and slate,	90%	11.1%
"	Buckwheat No. 1, good quality,	93%	7.5%
"	" No, 2, "	85%	17.6%
"	" No. 3, "	83%	20.5%
"	Culm No. 1, mixed with 20% soft coal slack good quality,	83%	20.5%
"	Culm No. 2, mixed with 20% soft coal slack, good quality,	77%	29.9%
"	Culm No. 1 (alone), good quality,	75%	33.⅓%
"	" No. 2 (alone), "	70%	42.9%

It can hardly be expected that such figures can be exact under the varying conditions, but they were obtained in actual practice.

Dr. Perrine:—The practice in steaming in California is very bad, and it is largely for this reason that the coal dealers are the only steam makers. The coal is purchased in California for the electric railroads and power plants on the basis of the production of pounds of steam per hour. The coal is entirely paid for by the thousand pounds of dry steam produced. The coal dealer has the option of using his own firemen or using the firemen belonging to the company he is supplying. Of course in either case the company supplied pays the wages of the men, but the coal dealer may take entire charge of the fire room and hire the employes, or he may simply have a representative there. The best coal that we get out there, the coal which has the highest calorific power, is Welsh anthracite, which is obtained by the largest dealers at about $6.00 per ton. I paid $11.00 a ton for it, and I can get a lower grade of bituminous for $10.50. But the largest dealers can obtain a lower grade of bituminous coal at about $4.50 a ton, but no coal could be had in California for less than about $4.50 a ton by the largest dealers, and those are people who charter their own ships and bring in coal by the shipload. The most of our bituminous coal comes from Australia and our anthracite coal comes from Wales. There is very little Pennsylvania anthracite used. That has to come overland and costs from $11.00 to $12.00 per ton. Some people who are very particular and want good hard coal buy it. One would expect that these men would work out thoroughly the best possible grates and the best possible methods of handling coal, but the greatest advance they have made consists simply in bringing from the boiler a steam jet to serve as a blower to the fire. That serves not only as a blower, but gives a flame to this Welsh anthracite coal which it does not possess without that agency. Only recently have some few of the younger engineers made careful tests with change of grate-bars and the use of the cheaper coals, and up to the present time they have not obtained very good results because the manufacturers are slow to see that the experiments may result in any great advantage. They buy steam, not coal, and they are reasonably satisfied with the price that the steam costs them, so they are not willing to put much money into change of furnaces, especially as the coal is controlled by a very close combination, and they do not know but that if they should generally introduce bituminous coal of a low grade, that then the bituminous coal of a low grade would be held at the same price as the anthracite of a high grade. Furthermore there is hesitancy on account of the fact that the low grade bituminous coal comes from Alaska and Washington, with which there are comparatively no return freights, so that while we can bring a little coal down from that country cheaply, if we should have to carry a great amount of coal it would mean freights only in one direction and the freight rates would run up. The coal is brought in the wheat vessels. A good deal of our flour goes to Australia and a great deal of our wheat goes to

England. The whole stock of California coal comes into the State during the autumn, when the wheat ships are arriving for their fall cargoes, and these combined elements have held the question of consumption at one point for a great many years, and as I say have directed steam users to the economic value of the very best coal that we can get, which is really a better coal than many coals you get here on the Atlantic coast. I do not think there is any, except possibly the gas coal that you have here in the east, that has as high calorific power as the Welsh coal.

PROF. R. B. OWENS:—I feel that one of the best directions in which electrical engineers can direct their efforts is in inducing the owners of small electric light and power plants, to keep a continuous coal and water record. Of course it is done in our large plants and in a few isolated ones. For instance, in the Board of Trade plant in Chicago, a continuous record of water and coal is kept and averages are obtainable which it is impossible to get in two or three ten-hour tests. Coals of all kinds are tried, and the number of pounds of water evaporated, under standard conditions, per dollar's worth of coal, is obtained, which is really the only proper way to express the value of coal, or any other fuel used for steam generation. In some of our large lighting plants, the cost of coal is now, I believe, less than the lamp breakage. It has come to be one of the smallest items of expense; whereas, in smaller lighting plants in interior towns, it is more than one-third the total expense of operation. In these latter, therefore, the coal pile must be watched with especial care, but as I said before, very little of value is obtained by short runs. For instance, it is possible to get from New River coal, an evaporation of 13 pounds, from and at 212, under proper conditions of firing. Captain Jones of Chicago, formerly of the Navy, last year made a test, using New River coal, of a well-known water-tube boiler fitted with a good automatic stoker, and after three or four preliminary trials, actually got 13 pounds—13.1 pounds evaporation, I think it was, from and at 212. No such record, however, has ever been made under the ordinary conditions of continuous service, or, is likely to be.

A MEMBER:—Is that per dollar's worth of coal?

PROF. OWENS:—No, per pound. It simply shows that short tests amount to very little. It is only when records are kept extending over months and perhaps years that anything of real value can be obtained.

MR. DOUGLASS BURNETT:—Before we change the subject, I wish to say that Mr. Foster has my own personal and hearty thanks for the great care that he has evidently bestowed in fishing out a lot of information which is certainly valuable—extremely valuable—and I think that one of the aims of the INSTITUTE should be to combine the science with the commercial side, and I believe that in this respect Mr. Foster's paper is perhaps the best paper that I have heard, because he combined what we are taught in our colleges, the work that we do in connection with our mechanical engineering, with the results obtained in commercial practice. I have encountered personally some of the difficulties that Mr. Foster has, and I know that when he is able to summarize 22 cases in which he can get accurately at the cost of power he has done a great deal of work. He has my personal thanks.

MR. W. H. RIPLEY:—In regard to what Prof. Owens says about the importance of keeping a close record, I noticed on Long Island a couple of years ago, where a plant was started, there was a large supply of coal on hand in the yards. The coal was of very good quality and high cost, and the plant was started on that coal. The engineer in charge was a man of a great deal of experience, and had studied a good deal besides his actual firing work. When the supply gave out, the directors of the company, who were not very far-seeing people anyway and had all along been complaining of the price of coal, got a chance to buy a quantity of very much cheaper coal—that is what they looked at, the price of it; and this man had been keeping very careful records of the evaporation per pound every day, and he made a weekly summary and a monthly report to the company, and kept track of the percentage of ash. The percentage of ash in the coal they started with was, I believe, about 8½ and with this cheaper coal the ash was over 13 per cent. After over two months of talk, presenting the matter to those directors who were mostly residents there, we finally convinced them that they were getting a smaller amount of steam, and that the increased amount of ash just about balanced the difference in price in the coals, but it took a long while, and I think that is an example of the difficulties that men in charge of steam plants have—that managers or purchasing agents look at the cost of the coal alone, and unless some very careful record is taken it is almost impossible in some cases to make any improvements in the cost of the steam.

THE PRESIDENT:—If the discussion is over, there will be some announcements.

MISS FARMER:—I have a telegram which should have been received on Monday, July 26th, which I will read:

MISS SARAH J. FARMER.

"I regret exeeedingly that recent absence abroad and urgent business engagements since my return have prevented the preparation of my intended paper on electric railways, and to my great disappointment I am also denied the privilege of attending the meeting of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS at the noble memorial you have established to the memory of your distinguished father.

'I am, however, with you in spirit, and, furthermore, by a coincidence which I hope may prove an auspicious augury, this day, the fiftieth anniversary of the first exhibition at Dover by Moses G. Farmer of the movement of a car by electricity, has seen the inauguration and first public demonstration of an electric train, properly speaking, that is, one in which each car is individually equipped with motors and all are electrically controlled from any desired point. This marks a new departure in electric propulsion as distinguished from locomotive practice. It is the logical sequence of the adoption of electricity for railway work, and to-day a train of six cars has been successfully operated by a boy of nine years.

"The advancement of the electric railway in the decade since the installation of the Richmond railway is unparalleled, and no advance in the industrial world has had a more widespread and beneficial effect on the social and moral well being of the community. In 1887 there were scarcely a dozen electric railways in existence, to-day there are 700 in the United States alone. Then there were scarcely 100 miles of track, now there are nearly 14,000 miles. From 150 cars, the equipment has grown to over 35,000, propelled by 52,000 motors.

"Prediction would perhaps be idle, but it would seem that we are entering on a new era of railway progress whose extent cannot well be limited, in which not only city but suburban, and in a large measure interurban, passenger traffic will be electric in all its essentials. FRANK J. SPRAGUE."

THE PRESIDENT:—I am sure we are all very much interested to hear this telegram read on this occasion. It is most unfortunate, however, that we do not have Mr. Sprague here in person, because his personality is particularly strong and interesting, but he shows some of it, I think, in his telegram.

I believe Prof. Owens has an invitation to present to the INSTITUTE. The INSTITUTE would be glad to hear it.

PROF. OWENS:—I have the pleasure of extending on behalf of the President and Board of Directors of the Trans-Mississippi Exposition, an invitation to the INSTITUTE to hold its next general meeting in Omaha. Every facility will be afforded for making the meeting a success. Probably in a great many years the west will not have such features of electrical interest as may be seen in Omaha next summer. I hope that some expression may be obtained from those present in this regard, for the sooner the place of meeting is decided upon, the easier it will be to make arrangements for a successful one.

MR. T. C. MARTIN:—Mr. President, I think most of us have listened to the invitation from Prof. Owens as a special Commissioner from the State of Nebraska with a good deal of interest and pleasure. It seems to me that after coming, as we have here, to the extreme eastern tip of the continent, it would at least be proper and in order that our next oscillation, as you might call it, should carry us somewhere toward the centre of the country. We have been inclined in our meetings to linger eastward and it is certainly high time that once more we turn our faces to the west; and perhaps to render the contrast complete I do not know that we could seek anything in sharper difference from the sweet serenity and peace of our surroundings here than the bustle and hurlyburly of the west, as we shall find it, proceeding from Chicago and staying a few days at Omaha during that exposition. I think, moreover, that we, as a body, owe a little to the State that our friend represents. I had the pleasure of being in Lincoln last year and I was deeply impressed with the magnificence, the splendor, the regal generosity with which that State had endowed her educational facilities, and particularly the eagerness with which they were seeking there to give further scope and larger aim, and higher purpose, to the scientific and technical training of her young men. If we go west upon such an occasion as this, we shall not only be doing something that Nebraska will deeply appreciate, but we shall be furthering the purpose which underlies the existence of the INSTITUTE itself. I would like, therefore, if it please you sir, to offer this resolution, which, I will say just by way of preamble, is not intended in anywise to commit us now. I do not think that that would be proper. I do not think it is perhaps within our province. The object of this resolution is simply to get from this meeting an expression of its feeling on the subject, and though perhaps this is not as large a meeting as it might be, we have rarely had a more representative gathering than at this time. Another fact I would like to mention is that we have a large number of members in the west; possibly the preponderance is west of the Alleghanies and certainly we do wish to extend our membership out west and the best way to extend it is to go west and go after the membership. My resolution is this:

RESOLVED that it is the sense of this meeting, that it is desirable to hold the next General Meeting of the INSTITUTE at Omaha and that the invitation, extended by Prof Owens be favorably referred to the Council for further consideration and early action,

MR. DUNN:—Mr. President, I desire to second this motion. I think that a meeting in the west next year would be particularly appropriate. I think that the holding of it at Omaha at the time of the Trans-Mississippi Exposition would enable us to assemble a large gathering, and when Mr. Martin mentioned the hospitality that we should find in the west it brought to my mind pictures of how well our western friends would receive us, and do everything in their power to make us comfortable and to make our meeting a success.

MR. STEINMETZ:—I think this motion is a very timely one. Our INSTITUTE has in the last years extended so greatly westward that the centre of membership undoubtedly lies considerably further west than the average meeting place. Now we have so many members in Chicago and San Francisco whom we have never seen and who possibly may come to Omaha, but who certainly will not come to us here, and since for years and years most of the meetings have been held here in the east and even in the far east, a meeting farther to the west would be very timely. I heartily endorse this motion.

MR. C. W. PIKE:—It appears to me there are three very good reasons why we should go to Omaha. In the first place there has been a good deal of criticism of the management of the INSTITUTE, because it is considered to be a New York concern. I know of course that that criticism is by no means just. At the same time it exists. I think it would do a great deal to dissipate that, if we did get into the habit more extensively than we have in the past of holding our meetings outside of New York, more especially in the western states. In the second place I have no doubt that we should have a larger meeting in Omaha than perhaps any place that we could choose, because we should have the Trans-Mississippi Exposition for one thing, and because people in the west think nothing of traveling a few hundred miles. In the third place, Prof. Owens has invited us. I should therefore most heartily second this motion of Mr. Martin to refer this resolution favorably to the Council.

The resolution was carried unanimously.

THE PRESIDENT:—I will take this opportunity to make an informal statement for the information of the INSTITUTE. As a delegate appointed by the INSTITUTE to represent it at the National Conference on Standard Electric Rules called together to formulate and promulgate one uniform code of electric rules for the whole country, I have to report that the Conference has successfully accomplished its work and that the code is printed. This Conference was composed of the following bodies: The American Institute of Architects, THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, The American Society of Mechanical Engineers, The American Street Railway Association, Factory Mutual Fire Insurance Companies, National Association of Fire Engineers, National Board of Fire Underwriters, National Electric Light Association and the The Underwriters' National Electric Association; these being practically all of the bodies which have any direct or even indirect interest in this question, and it would therefore seem to be a particularly complete organization. In fact, I think it can be said to be one of the most complete and important aggregations of technical and commercial interests that was ever called together for a specific purpose of the kind, and I think it is a matter of congratulation that it was able to perform the work for which it was organized. I can also say for the information of the INSTITUTE that the influence of the INSTITUTE and the fact that it had taken this somewhat unusual step, had a most favorable effect in securing the success of this Conference. I am sure that if this INSTITUTE had held itself aloof, as it has in the past in such matters,the Conference would not have been a success. I will report formally to the Council and strongly recommend the approval of this code by the INSTITUTE, and I feel warranted in making this recommendation in view of the fact that it has already been adopted by several of the influential bodies, in fact more than one-half of those represented in this list I have given to you.

The next paper on the list is on "Efficiency and Life of Carbons in Enclosed Arc Lamps," by W. H. Freedman, H. S. Burroughs and J. Rapaport. The authors are not present and as I am somewhat familiar with the paper I will read it and will call upon Vice-President Steinmetz to take the chair.

Mr. Steinmetz took the Chair and Dr. Crocker presented the paper as follows:

A paper presented at the 14th General Meeting of the American Institute of Electrical Engineers, Eliot, Me., July 28th, 1897, Vice-President Steinmetz in the Chair.

THE ENCLOSED ARC LAMP.

BY W. H. FREEDMAN, H. S. BURROUGHS AND J. RAPAPORT.

Statistics show that the enclosed arc lamp is not only rapidly increasing in the point of numbers installed, but actually replacing, in many instances, the open arc lamp. The fact that one set of carbons will last from 75 to 150 hours, according to the make of the lamp, is in itself sufficient to explain the successful and rapid introduction of this form of lamp. Feeling, however, that there were many facts and much data that could be presented in relation to the enclosed arc lamp, a large number of tests were carried on, the main results obtained being presented in the following paper.

Obtaining samples of the Manhattan, Helios, Bergmann, Imperial, Pioneer, Thomson 75-hour and Thomson 100-hour lamps, tests were made bearing upon the relation between length of arc and voltage across the arc, the regulation, life of carbons, ratio of consumption of positive and negative carbons, and the distribution of light.

The method was adopted of assigning a number to each make of lamp, and using that, instead of the name of the lamp, in stating the results.

MECHANISM OF THE ENCLOSED ARC LAMP.

All of the enclosed lamps now on the market, work on the same general principles. They are placed singly across the ordinary incandescent lighting circuit, and are regulated to take, approximately, 80 volts across the arc, the rest of the potential being consumed in the regulating solenoid and extra resistance (shown in Fig. 1). There is a marked difference between all of these and the ordinary open arc. The standard current is five amperes, the arc being about $\frac{5}{16}''$ long, while the carbons burn nearly flat instead of taking the shape as in the case of the open arc. This makes a change in the distribution of the light, com-

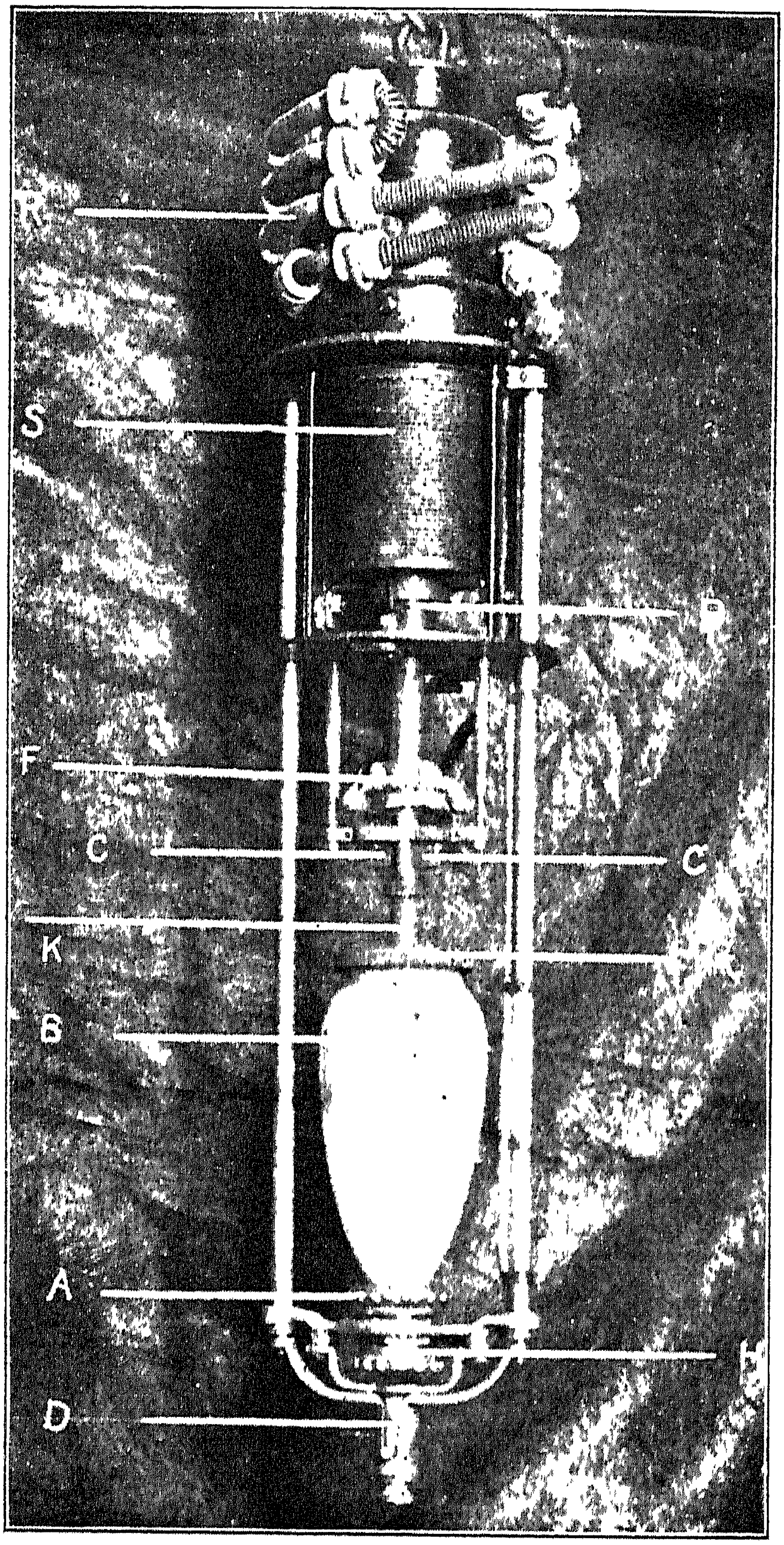


FIG. 1.—Carbon Feed Lamp. Lamp is about 30″ long, whereas lamps with Carbon Rods come as long as 46″.

R Extra Resistance.
S Solenoid
P Plunger with Dash-pot attachment.
F Friction Clutch.
CC Contact pieces of Clutch.
K + Carbon.
G Gas Cap.
B Inner Globe.
A Inner Globe Holder.
H — Carbon Holder.
D Holder for Outer Globe.

pared with the open arc, which will be shown by curves later on. Fig. 2 shows the difference in appearance of the carbon in the two styles of arc. The enclosed arc burns flat on the top or positive carbon, the lower or negative one becoming slightly convex. The arc itself does not remain in any one spot, but wanders all around the flat ends. In the case of large carbons, this is objectionable, as it causes rather heavy shadows to be cast, which to a large extent, can be prevented by the use of proper globes. The experiment was tried of rounding the ends slightly. This arrangement did away with the shadows, but the carbons burned flat again in a very short time.

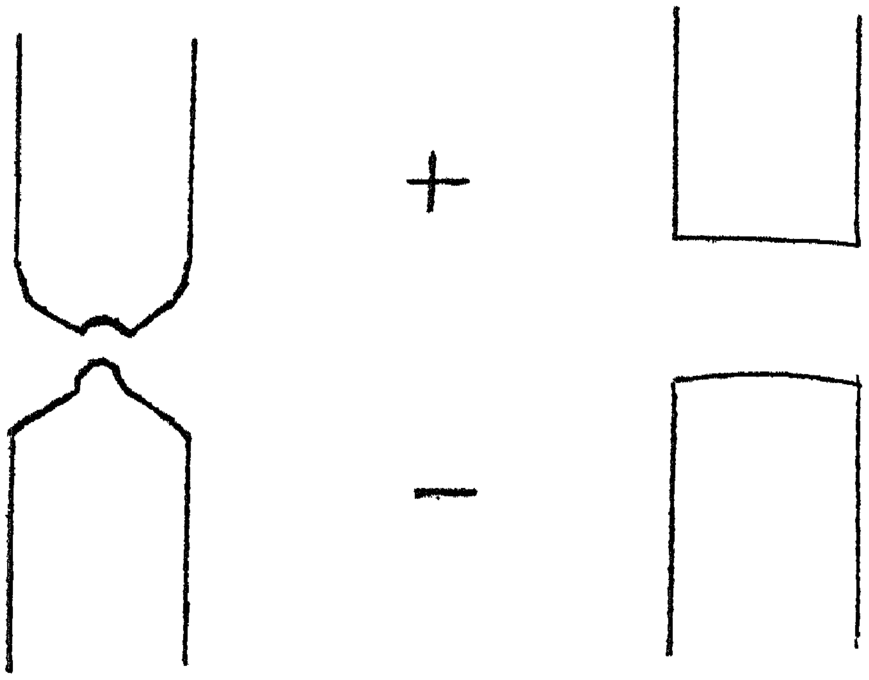


FIG. 2.

The current passes through the extra resistance, the solenoid and the carbons, in series. This series arrangement makes a very simple lamp, with very few parts, and working much steadier than the open arc lamp. When no current is passing, the carbons touch; the moment the current is thrown on, the core is drawn up, carrying the positive carbon by a friction clutch. The negative carbon is fixed in a holder or socket, at the bottom of the lamp.

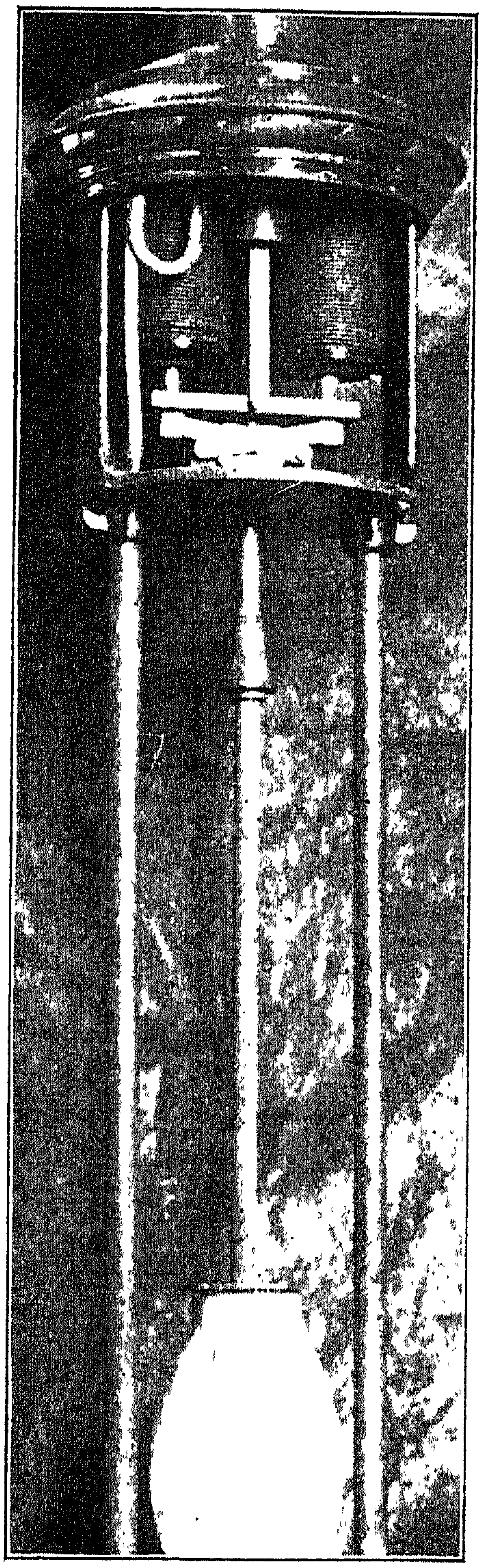


FIG 3.

The simplest form of friction clutch consists of a straight horizontal rod fastened to the end of the plunger of the solenoid, and having at each end an arm so pivoted that these two arms cross each other like a letter X (as shown in Fig. 3). At each lower end of these arms is pivoted a friction piece, with either a rounded or a V-shaped surface, that grasps the rod holding the upper carbon. Lifting the upper ends causes the lower ends to come nearer together, thus gripping the rod. The carbon and its rod are dropped when the device falls far enough to touch a stop that prevents the lower part of the clutch from coming down any further. A novel departure from this form of clutch consists of a cylindrical piece of brass, fitting around the rod, and having its upper end grooved to hold a row of steel balls. These are held in place by a conically-shaped cup. When the inner cylinder rests on the stop, the cup, which is attached to the plunger, descends far enough, by reason of its sloping sides, to release the friction on the balls and the carbon rod falls. When the core is drawn up, the cup follows, the balls being caught in the apex of the cup, and the rod is drawn up.

Fuses should be put in circuit with each lamp, and as the first rush of current is from 40 to 240 per cent. of the steady value, according to the make of the lamp, the fuse must be heavy enough not to blow when the lamp is first thrown in. In the case of lamps having a large flush of current, the lamp is not so well protected against an accidental heavy current, as the fuse must be of greater carrying capacity than in the case of lamps with a small flush of current, and may not blow until the lamp has been seriously overheated. One effect of high temperature around the working parts, is to make the brass rod that carries the upper carbon, stick, the surface losing its smoothness, so that in some cases it is necessary to take the rod out and polish it. The current is usually carried to the upper carbon by means of two brushes pressing on this rod. As the carbons wear away, the armature of the solenoid gradually descends, the current remaining practically constant whatever the position of the plunger, until it reaches the stop that releases the carbon from the friction clutch; the carbon then falls and strikes the lower one, but is immediately picked up again,—the light sometimes going out and sometimes remaining. This process, however, occurs at comparatively long intervals as the core has a play of $\frac{3}{8}''$ to $\frac{1}{2}''$ before the stop is reached. The positive carbon wears away at the rate of .05 of an inch, approximately, per hour, and the negative at half this rate; there will consequently be from 5 to

8 hours between the times of the resetting of the core to its top position. The open arc lamp, allowing a consumption of one inch per hour, feeds about 15 to 20 times as much.

A good lamp should have the following points, the determination of which was one of the objects of our experimental work:

Long life for one set of carbons;

Simple and light, but strong mechanism;

Lamp must be short, for use in low-ceiling rooms;

Must cast no shadows from the carbon points, and it must not be necessary to use very dense globes to obtain this result;

Smallest possible amount of deposit on the inner globe;

Smallest possible flush of current at start;

Lamp should pick up immediately when the carbons have fallen together;

Carbons should drop immediately at feed and if the arc should break;

Minimum hysteresis in the core and no friction of the moving parts sufficient to cause sticking;

Lamp should be so insulated that when the current is on, there is no uninsulated portion exposed;

The shell of the lamp should be readily removable so as to expose the working parts;

The outer globe should be easily removable and so fastened that, when hanging down it cannot be dropped or broken;

Old carbons and inner globe must be easily removable;

Both globes must admit of easy cleaning;

It should be easy to replace and centre the carbons;

The lower carbon holder and inner globe holder must be held firmly in place, and the arrangement for making the small bulb air-tight at the bottom should have no tendency to crack the glass or get it out of centre;

Regulating mechanism should give the smallest possible flickering of the light;

The dash-pot should be firm enough to resist sudden changes, but must not be so much so that it is slow in getting to its normal position.

LENGTH OF ARC.

In order to measure the length of the arc for different values of the voltage across it, the image was projected on a screen, on which the diameter of the carbon and the length of the arc were measured. The former being known, the true value of the length of the arc was determined by simple proportion. The results are given in Table I, and shown graphically in Fig. 4.

TABLE I.

VOLTAGE ACROSS ARC.	LENGTH OF ARC.
83	0.326″
82	0.316″
76.5	0.271″
71	0.217″
67.5	0.184″
62	0.130″
60	0.125″
35	0.011″

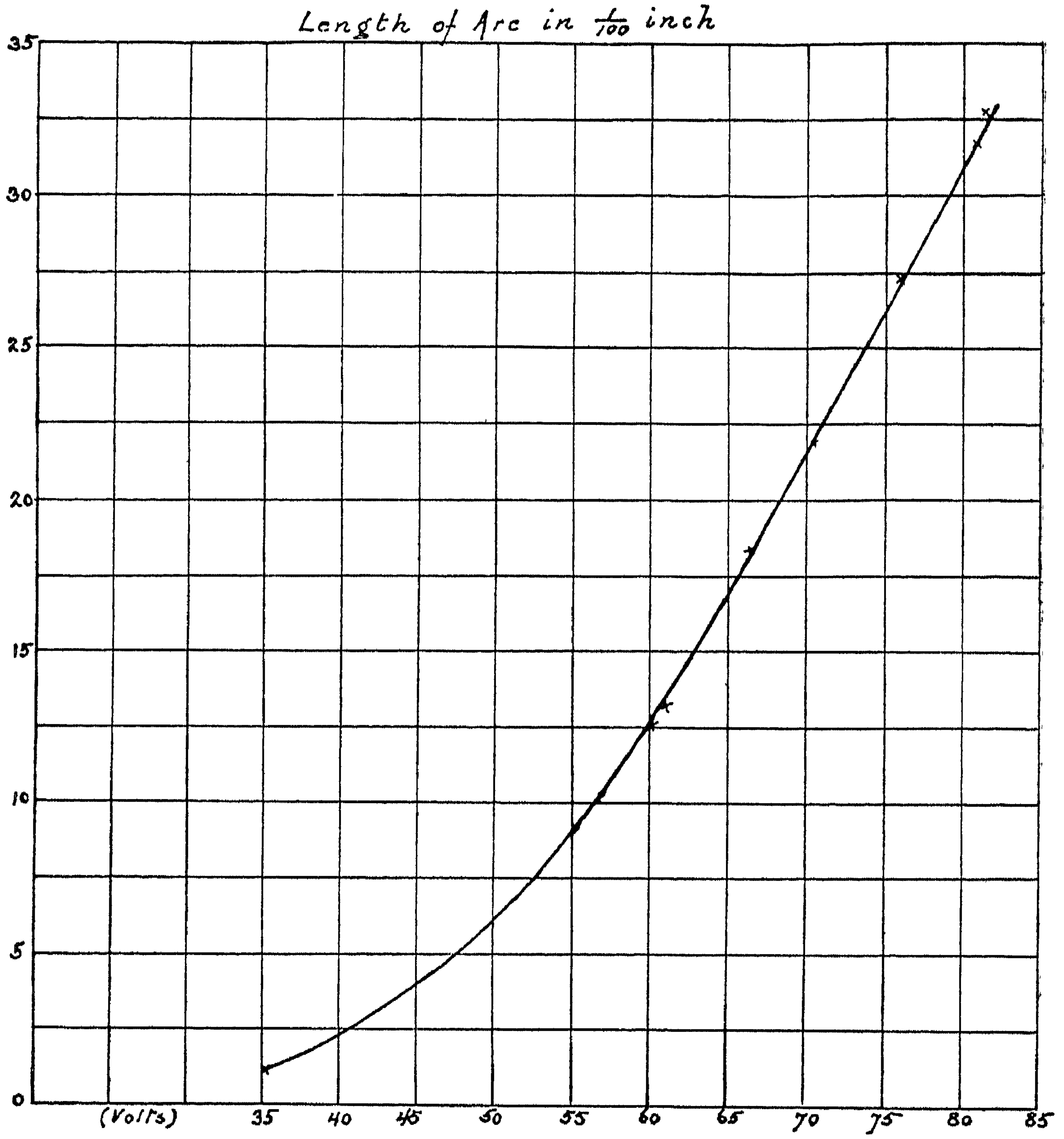


FIG. 4.

REGULATION.

The simple regulating mechanism of the enclosed lamp has a very great advantage over that of the ordinary open lamp. The series mechanism is not applicable to short arc lamps, as a given variation makes a large proportional change, whereas this is obviated by using a long arc. The current and voltage variation in both styles of lamp at starting, each on a constant potential circuit of 115 volts and the open arc being one of two in series, are shown in Table II and Fig. 5.

TABLE II.

TIME.	ENCLOSED ARC.		OPEN ARC.	
	Voltage.	Current.	Voltage.	Current.
0	74.	8.1	29.	18.
1 second	74.5	5.2	—	—
15 "	74.5	5.0	33.	19.4
30 "	75.	5.1	30.	21.
45 "	77.	4.8	—	—
1. minute	75.5	5.3	25.	22.
1.5 "	76	5.1	35.	18.6
2. "	78.	4.8	38.	18.
2.5 "	78.	5.0	—	—
3. "	81.	4.6	40.5	17.1
3.5 "	80.	4.6	—	—
4. "	80.	4.7	43.	16.1
4.5 "	77.5	5.0	38.	20.6
5.5 "	77.	5.2	—	—
6.0 "	79.	4.8	42.	19.0
6.5 "	79.	4.9	—	—
7. "	77.5	4.9	41.	16.4
7.5 "	80.	4.7	42.	16.
8. "	79.	4.9	41.	16.4
8.5 "	81.5	4.6	—	—
9. "	83	4.3	43.	14.9
9.5 "	79.5	4.8	42.	15.5
10. "	76.5	5.1	44.5	14.
10.5 "	76.	5.2	—	—
11. "	78.	5.0	41.5	14.6
11.5 "	81.	4.7	44.	8.
12. "	80.	4.5	42.5	8.
12.5 "	79.	4.6	—	—
13. "	81.5	4.3	42.8	8.9
13.5 "	76.	4.9	45.	7.
14. "	79.	4.6	45.5	7.2
14.5 "	80.	4.3	38.5	11.
15. "	79.5	5.1	36.	9.8

The voltage is that across the arc. The normal currents were 4.75 for the enclosed and 8 for the open arc lamp.

The normal voltage across the arc, for 5 amperes, in the enclosed lamp is 80. This gives 400 watts expended at the arc, the rest, depending upon the voltage of the circuit, being wasted in the extra resistance. On a 110-volt circuit, this would give $72\frac{7}{10}$ per cent. of the energy supplied to the lamp spent at the carbon points. Eighty to 85 volts seems to be as high as is desirable to get the best regulation. Some extra resistance is necessary for regulation, as a given change in the resistance of the arc will make a less change relatively in the whole resistance when this is large.

It might appear advisable to run a special circuit of lower voltage to feed these lamps if they are of sufficient number. To determine how low the voltage may be carried on a regular commercial lamp such as is supplied for the standard voltage, the external resistance was gradually cut out until the regulation of the current began to get poor. The lamp tested had an extra resistance of 6 ohms. The solenoid was very nearly one ohm.

On the external resistance being cut down to 3.1 ohms, the current became 4.8 amperes, while the voltage across the arc was 78 and across the lamp 100. No appreciable change was noticed in the steadiness of the lamp. This arrangement consumes 480 watts, total, and 374 across the arc, which latter remains practically the same. On a 115-volt circuit, where the lamp is normally run, the watts per lamp are 552, making a saving for this particular case of 72 watts. For every 100 lamps on the 115-volt circuit, 113 could, therefore, be run on the 100-volt circuit for the same number of watts consumed.

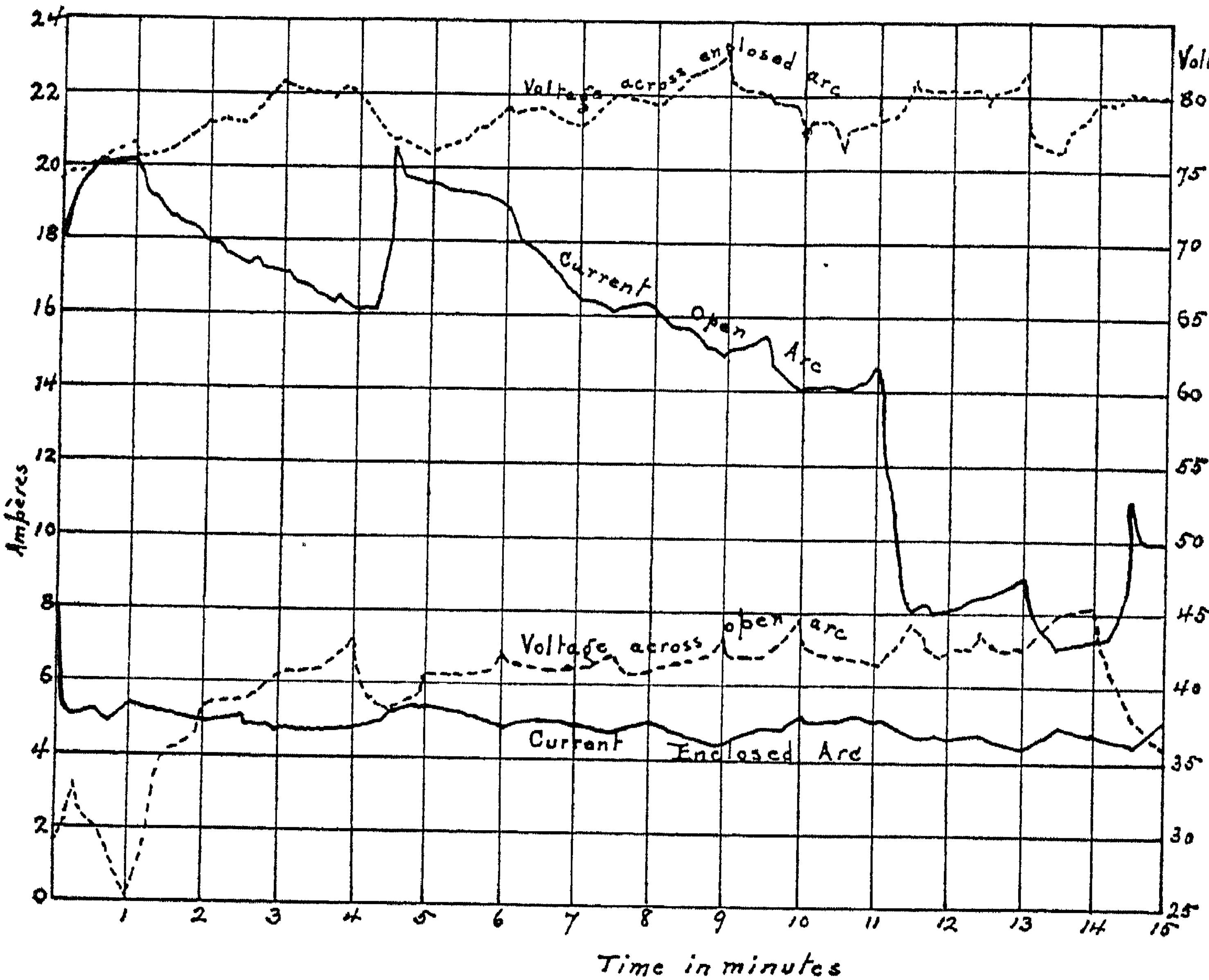


FIG. 5.—Comparison of Open and Enclosed Arc Regulation.

The external resistance was next reduced to 2.3 ohms when the current became 4.85 amperes, the voltage across the lamp 95, while across the arc it remained at 78. As the extra resistance is cut out, the value of the current is slightly increased. At this voltage the current was too unsteady and caused considerable flickering. For outdoor use this would not be noticeable, but for indoor use, such as reading and the like, it would be very ob-

All the lamps tested, showed flickering on a sheet of paper held a few feet away from the lamp. This experiment of lowering the voltage was performed with a small Edison machine, varying the field resistance to give the desired voltage.

Table III will be of interest in showing the steadiness it is possible to get, in current and voltage across the arc. The readings were made every two seconds on lamp No. 7. The results are also plotted in Fig. 6. Considering that the arc is constantly moving, and that the external voltage is not absolutely steady, the regulation is very good.

The largest swing noticed was from 5 to 5.3 amperes. Some of the lamps vary considerably in voltage at the start, taking

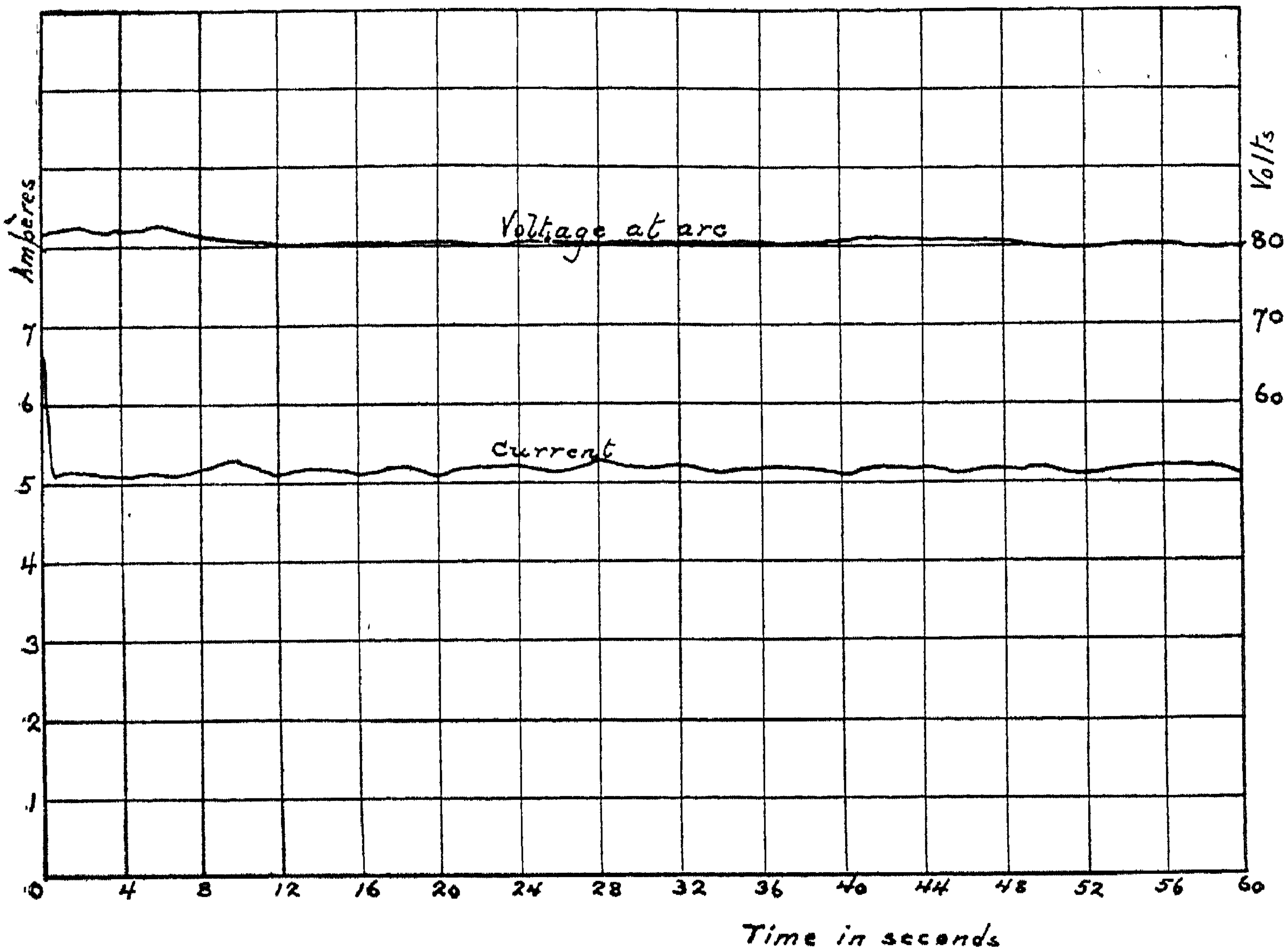


FIG. 6.—Current and Voltage Curves of Lamp No. 7.

TABLE III.

VOLTAGE.	CURRENT.	VOLTAGE.	CURRENT.
82	6.75	80.5	5.2
82.5	5 2	80.5	5.1
82	5.1	80.5	5.2
83	5.1	80	5.2
81.5	5.2	80.7	5.1
81	5.3	81	5.2
80.5	5.1	80.5	5.2
80.5	5.2	80.5	5.1
80.5	5.1	80.5	5.2
80.5	5.2	80.2	5.2
80.5	5.1	80	5.1
80.5	5.2	80	5.2
80.5	5.2	80.2	5.2
80.5	5.1	79.5	5.2
80	5.3	80	5.1
80.5	5.2		

about five minutes before their average voltage can be determined. The above lamp remained the same during its further run.

Table IV shows the initial rush of current compared to the average.

TABLE IV.

LAMP.	INITIAL CURRENT.	AVERAGE CURRENT,
1	8 to 9	4.75
2	9 to 9.7	5.0
3	8.5 to 9	4.9
4	12	5.0
5	7.5	4.9
6	11.3	5.15
7	6.75	5.15

This also shows the effect of loose and stiff dash-pots. The former have the advantage of taking small initial current, but are slower in falling and allowing the carbons to touch in case the arc breaks. With stiff dash-pots the carbons are forced together almost instantaneously. No better regulation, however, is secured during the ordinary running of the lamp.

All the lamps having rods to hold the upper carbon are necessarily very long, but this can be obviated by using what is called a carbon feed. The carbon fits into a small sleeve at the top, but the friction clutch grasps the carbon itself. This, however, gives poorer regulation, the light flickering more than when a carbon rod is used.

With brass rods, the method used for making contact is to to employ a pair of brushes at the top. One of the lamps tested does not rely on this method, but uses a flexible asbestos-covered wire reaching to the end of the rod. This is an advantage over the brushes, as contact is sure to be made. When a lamp has been run for some length of time, getting the mechanism thoroughly heated, the rod gets sticky from what appears to be shellac. In one case noticed, the rod was so discolored and dirty, after about 200 hours use, that the current would not pass from the brushes to the rod, the carbons being together. This shows the necessity of cleaning the rod at the end of every run. The rod must be easily and quickly detachable, or else so arranged that it can be cleaned throughout its whole length.

To get an idea of the variations in current of the different lamps, the ammeter in circuit was watched, and the data obtained is given in Table V. No lamp remains absolutely steady for more than a few seconds at a time.

TABLE V.

LAMP.	REGULAR VARIATIONS.	OCCASIONAL VARIATIONS.
1	4.5 to 5.0	4.5 to 5.3
2	4.5 to 5.5	
3	4.7 to 5.1	4.3 to 5.4
4	4.7 to 5.2	4.5 to 5.4
5	4.7 to 5.1	4.6 to 5.2
6	4.9 to 5.5	Flickers considerably.
7	5.0 to 5.25	5.0 to 5.4

The best regulation was obtained from lamps Nos. 3 and 7. Although the arc has more chance to move about on the $\frac{1}{2}''$ carbons than on the $\frac{7}{16}''$, lamp No. 3, using the latter, gave no better regulation than the one with the $\frac{1}{2}''$ carbons.

LIFE TESTS.

The life of a lamp for one trimming, depends on a large number of conditions, most of which are self-evident.

1. It is influenced by the size and quality of the carbons. The carbons will not run exactly the proper diameter, even though of he same make. This, while hardly noticeable to the eye, is discovered when it is found impossible to slip the carbon through the gas cap or in the lower socket and hole through the bottom.

2. The life depends upon the current strength. This varies gradually during the run of the lamp, on account of the plunger, aused by the wasting of the upper carbon. The following figures will give an idea of this change:

With upper carbon full length of 12″, the current taken by the amp was 5.2 amperes. Carbon 9″ long, the current was only 5.05 mperes; while, when carbon was only 6″ long, its final length, he current was 4.85 amperes.

3. The size of the enclosing globe affects the life, it being less by a slight amount for a smaller globe. All the other conditions being the same, a lamp having a smaller globe will, during a given run, have its globe replenished with air from the outside ftener than if it had a larger globe.

Table VI gives the carbon consumption in inches per hour or 5″ and 6″ globes.

TABLE VI.

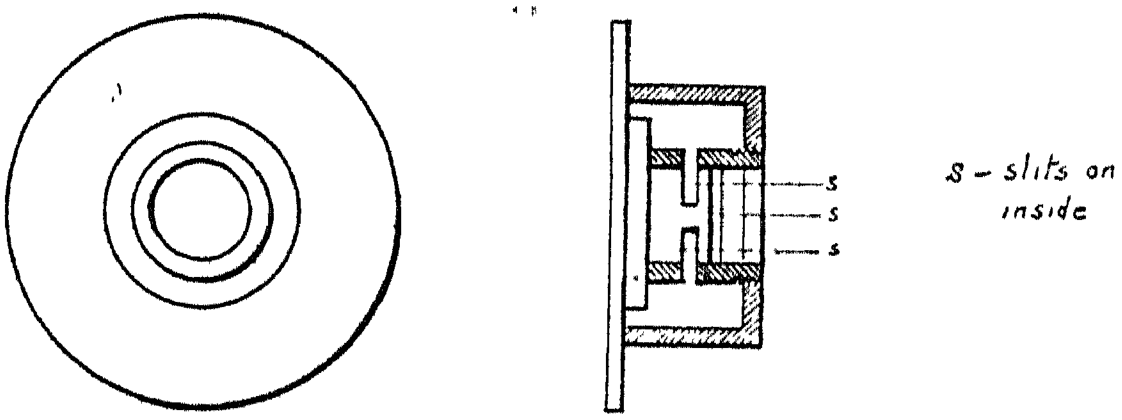
CONSUMPTION.	5″ GLOBE.	6″ GLOBE.
Positive	.067	.0687
Negative	.034	.029
Total	.101	.0977

4. The rate of consumption of carbon varies with the height f the arc in the globe. Although the current decreases in value

as the upper carbon is consumed, the total consumption per hour is increased as the position of the arc goes downward in the globe. The measurements given below, in Table VII, show this, which is a result of the increased circulation caused by the heat of the arc being lower in the bulb.

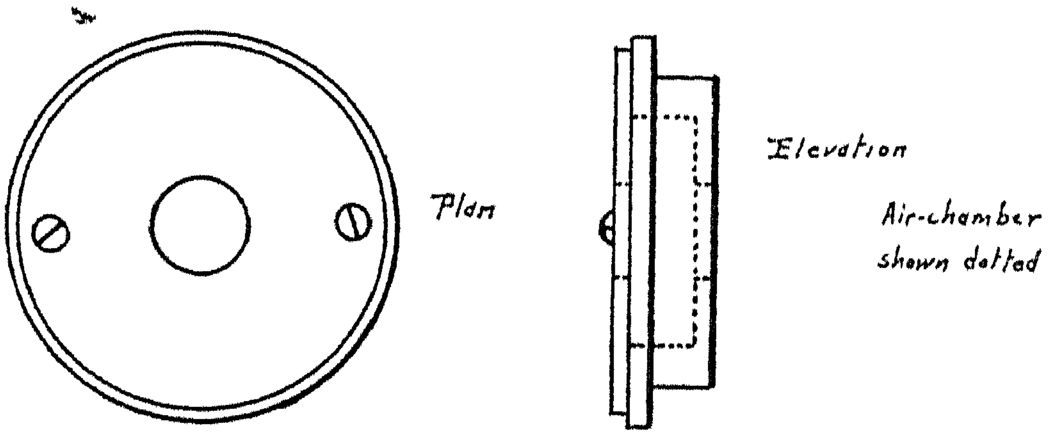
TABLE VII.

POSITION OF ARC IN BULB.	CONSUMPTION PER HOUR. Positive,	Negative.	Total.
Top	.070	.024	.094
Middle	.074	.034	.108
Bottom	.079	.039	.118



Plan of top piece with bottom removed

Elevation and part section through centre



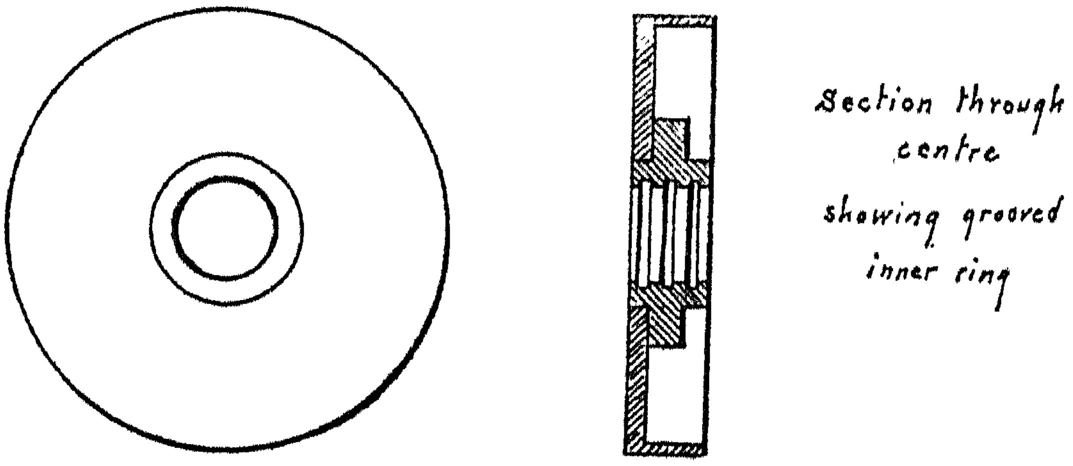


FIG. 7.—Gas Caps. Half actual size.

At the middle of the bulb the consumption per hour is 14% greater than at the top; at the bottom it is 25% greater. These figures are for $\frac{7}{16}''$ carbons, and are the largest for any of the lamps tested.

5. The form of gas plug used also influences the life. They

vary in form from a simple circular plate with the hole for the carbon grooved in two circles parallel with the plane of the disk, to the arrangement having a chamber fitted with slits through that wall which is next the carbon. The object of this chamber is to obstruct the circulation as much as possible, and yet have sufficient air to keep the carbon from depositing on the globe in excessive quantities. For some reason the consumption of negative and positive in one of the lamps having this latter form of cap is in the proportion of from 1 : 5 to 1 : 10. In all the other lamps the ratio of consumption of positive and negative carbons varied from 1.7 : 1 to 2.9 : 1. Since a slow consumption of the negative carbon keeps the arc well up in the globe, it gives an advantage over the other lamps in producing a larger area of distribution of light at the end of the run. On a horizontal plane it will give a little less, as the coating is heavier at the top of the globe. This holds, however, for a continuous run only; the ratio of consumption being 1:3 for intermittent runs. This shows how the effect of the gas cap is neutralized by allowing fresh air to enter at intervals.

Fig. 7 shows the different styles of caps.

6. Whether the run is continuous or intermittent will make a difference in the life, although only slight. Theoretically, the life should be less for the intermittent test than when the lamp is kept burning without any stops. The stoppage allows fresh air to get in, thus increasing the consumption. When the current is thrown off a lamp, it is to be noticed that the co gas catches fire from the inrush of air and forces its way out against the incoming currents, so that in some instances the force is sufficient to make the cap chatter in its place. The blue flame produced disappears in a time varying up to ten seconds. The results we obtained were irregular, but show that the life is about the same whether the lamp is burning steadily or at intervals, as shown by Table VIII.

TABLE VIII.

TEST.	STEADY RUN.	INTERMITTENT RUN.	
	Life in Hours.	Life in hours.	No. of Stops.
a	124	128	21
b	130	143	15
c	28	25.5	22
d		143	15
		141	20
e	128	112	18

Test *c* is not the full life. An accident compelled the stoppage of the continuous test after 28 hours, and the intermittent test was then carried on till the same amount of carbon had been consumed. It will be observed that in two cases the life was longer for the non-continuous run. Another test not given above, showed almost exactly the same loss of carbon for each run, the consumption for a given number of hours being measured.

To find, theoretically, the amount of carbon consumed with intermittent use, we can calculate the weight of oxygen the bulb contains when filled with fresh air, and from this determine the amount of carbon burned before the admission of any more fresh air. For example, one of the bulbs contained 18.8 cubic inches of air. Since the amount of oxygen contained is one fifth of this, and a cubic inch weighs 343 grains, the bulb contains when filled with fresh air, 129 grains of oxygen. In forming co gas, this amount of oxygen would require .967 grain, or approximately one grain of carbon to combine with. Carbon, at a specific gravity of 2, weighs 505 grains per cubic inch. If the carbon is ½″ in diameter, its section is very nearly .2 sq. in. and a piece one inch long will have a volume of about .2 cu. in. and weigh approximately 100 grains. Then, if one grain of carbon is consumed for each filling of the bulb, it means that .01″ in length has been used. Taking .07″ as an average total consumption per hour and that only .01″ is consumed by the air in the bulb at starting, it will take 7 of these renewals to consume an amount of carbon equal to one hour's regular run. That is, if the lamp

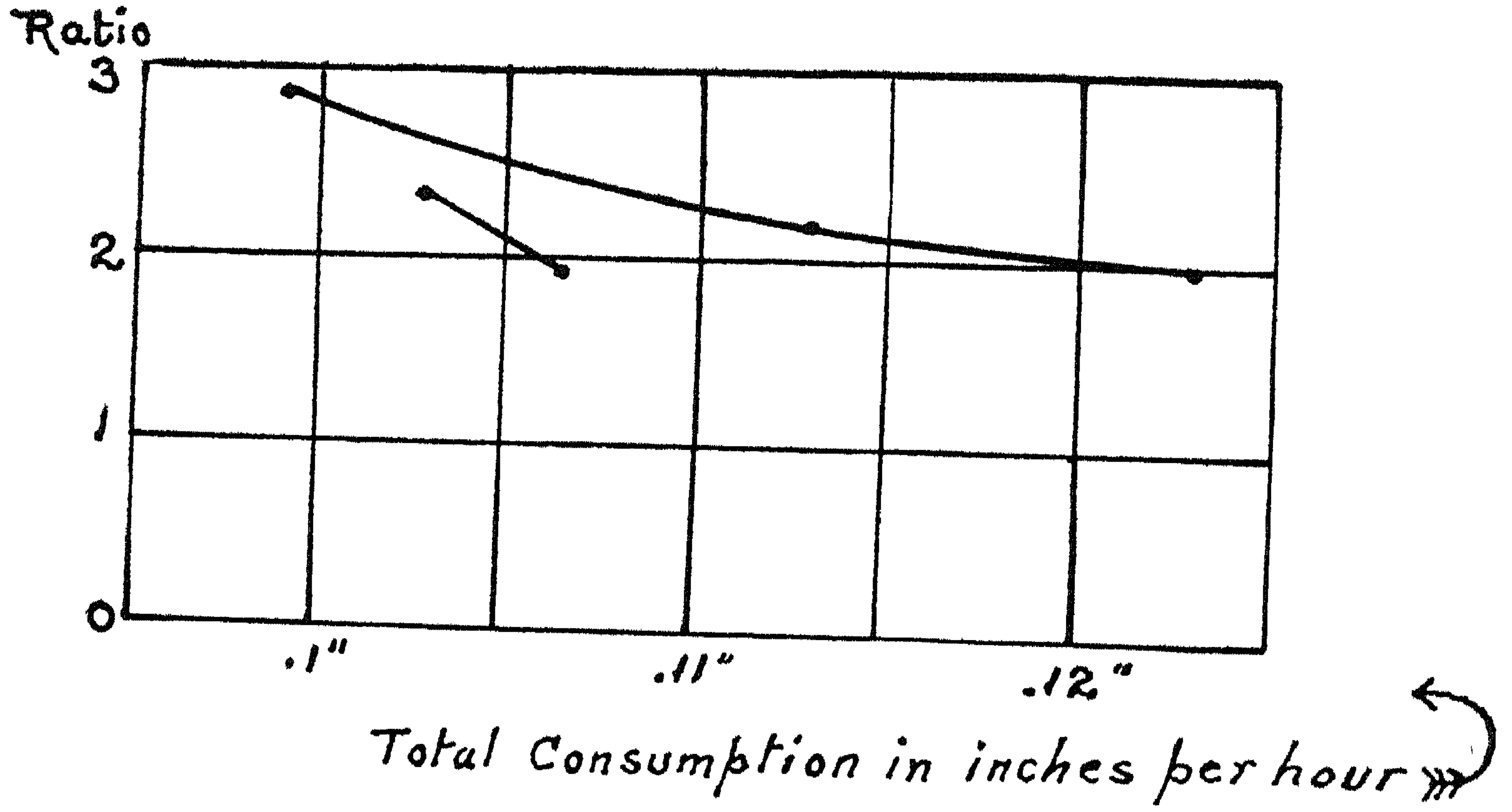


FIG. 8.

is run for a few minutes, sufficient theoretically to exhaust the oxygen in the bulb, and if this is done 7 times, it will use as much carbon as if the lamp had been running steadily for one hour. Therefore, taking 4 hours as an average run, a lamp burning 140 hours would have 35 stops, equivalent in consumption to 5 hours run, and on this basis would consume carbon as if it had burned continuously for 145 hours.

7. Some of the lamps make use of an air-tight outer globe to keep down the supply of air. This may make a slight difference in the lamp's life, but it has the disadvantage of raising the temperature inside the lamp to a very high point, making it necessary to use an insulation that will not char from the effect of the heat. It may also cause a coating of shellac that is originally put on the solenoid, to deposit on the brass rod, insulating it and causing it to stick. A thermometer placed inside the extra resistance in a lamp that was open at the top, showed 324° F. The temperature of the air around the clutch in a lamp with ventilating holes was 280° F., and that of the shell, 134° F. The inside temperature of a tightly closed lamp would probably be considerably higher.

Ratio of Consumption of Positive and Negative Carbons.

For a given lamp, the ratio decreases as the total rate of consumption increases, not only for different sizes of globes but also for different parts of the same globe. This is shown by Fig. 8 and Table IX.

TABLE IX.

Consumption in Inches per Hour.			Ratio.	Remarks.
Positive.	Negative.	Total.		
.070	.024	.094	2.87	Different parts of same globe.
.074	.034	.108	2.20	
.079	.039	.118	2.02	
.0687	.029	.0977	2.37	Different globes.
.0670	.034	.101	1.97	
.0617	.00617	.0678	10.	$\frac{7}{16}''$ carbons, largest ratio observed.
.0509	.0227	.0736	2.24	$\frac{1}{2}''$ carbons.
.0467	.0216	.0673	2.16	
.0543	.0217	.076	2.50	
.046	.027	.073	1.70	
.048	.023	.071	2.08	

It will be observed that the smallest total consumption was obtained with a $\frac{7}{16}''$ carbon, showing very markedly the effect of the gas cap. The usual method of renewing the carbons is to use the remainder of the upper carbon for the negative in the next run. In the case of the lamp just cited (No. 3) the upper carbon left is about ½″ shorter than a new lower carbon, but since the life of this lamp is so prolonged the shortness would be no drawback. The lower carbon might even be used for two continuous runs, if the position of the arc in the lower portion of the globe is not objectionable.

The long life of the enclosed arc may be considered its chief advantage over the ordinary open arc, the saving in carbons and trimmers' expenses being very large. The old style of lamp requires two carbons for each trimming, and lasts 6 or 8 hours. The enclosed arc requires to be trimmed about $\frac{1}{15}$ or $\frac{1}{20}$ as often. Furthermore, each re-trimming costs less. For, although the cost per thousand for the same size carbon is greater for the enclosed arc, being $23 for 12″ × $\frac{7}{16}$″ rods, only one is required for re-trimming, while the open arc needs two, costing $18.70 per thousand for 12″ × $\frac{7}{16}$″ rods and $8.30 per thousand for 6″ × $\frac{7}{16}$″ rods; so that one thousand re-trimmings cost $23 for the enclosed lamp, against $27 for the open lamp, or a saving of $4 per thousand trimmings in favor of the enclosed arc lamp.

PHOTOMETRIC TESTS.

The figures given for the candle power of the lamps when using different globes are only approximate on account of the difficulty caused by the great difference in value of the standard source of illumination and the arc, the very marked difference in the color of the light (the arc being violet around the horizontal plane and white below it, while the incandescent lamp gave an orange light even when run above its normal voltage), the wandering of the arc, and the personal error in comparing the lights. In making comparisons of the intensity of the lights we used a pencil photometer, determining the relative values of the arc and the standard lamps by means of the shadows cast by a pencil on a white card, the illumination at different angles being obtained by raising the lamp with a rope and pulley. If the carbons were not kept exactly centered, the angle of maximum intensity could be shifted all around. Our figures for the different angles were obtained by taking the mean of about ten readings, taken around the surface of a cone whose slant is the same angle as that of the given angle. These mean values were then plotted, and from the area of the resulting curve the value of the radius of a circle of equal area is calculated. This radius gives the value of the mean hemispherical, or spherical candle-power, as the case may be.

By means of a standard candle (British, having a 45 millimetre flame) an incandescent lamp was calibrated at a constant voltage, obtained by the use of several resistance boxes in parallel and all in series with the lamp. This lamp was recalibrated at frequent intervals.

The inner globes furnished by the different manufacturers vary in density, from a globe that will show the unlit carbons inside very plainly, to a form that is so dense as to be translucent, but not transparent. This latter form diffuses the light better than a thinner globe, although cutting off more light. All the opal globes, when held up to a window, show a reddish orange color, which has the effect of softening the violet light cast by the naked arc. The use of a fairly dense opal inner globe and a light outer globe gives a soft light that is pleasing to the eye and free from shadows. Figs. 9 and 10, which are reproductions from photographs, show the shadow cast when a clear inner globe is used, and the softening effect of an opal inner globe, which makes a light entirely free from shadows, not even the side rods showing. When an opal globe is used, it appears like a solid source of light. It is this effect that does away with the shadows of the side rods. The shadow cast by the bottom of the lamp is also made very small, so that the effect to the eye

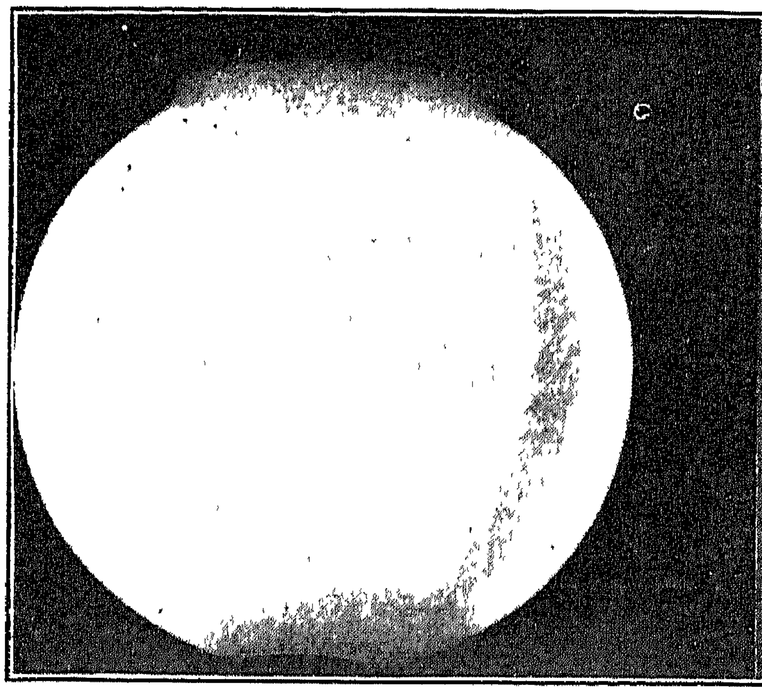


FIG. 9.—Shadows of Side Rod and Carbon Tip from use of Clear Inner Globe.

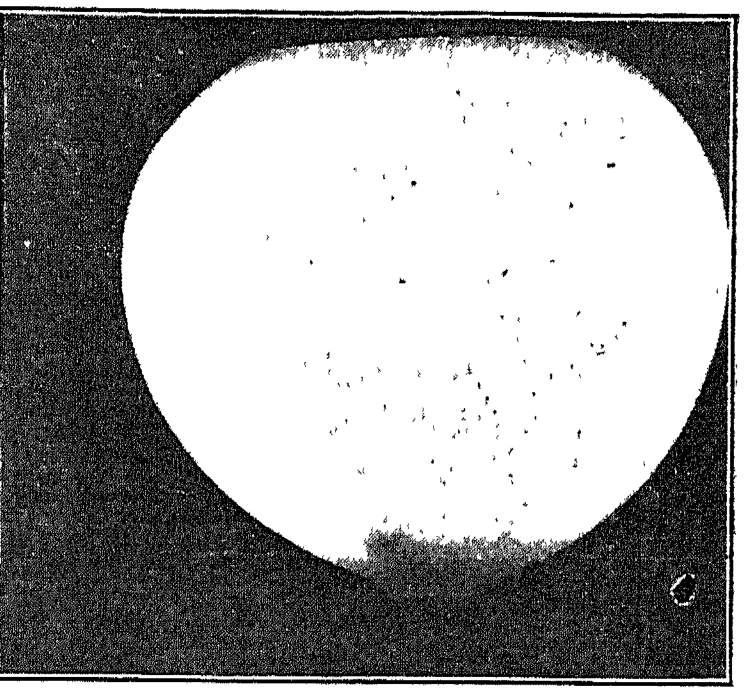


FIG. 10.—Opal Inner Globe, used for making Outer Globe free from Shadows.

is that of a bright, even illumination, apparently as much as the illumination from the naked arc, although the intensity has been cut down considerably by the globes. This is due to the fact that a light very intense in one spot seems to give no more illumination than a diffused light of smaller total value.

The distribution given by an open arc lamp is not the same as that from an enclosed arc lamp. The maximum in the latter is at an angle of 25 degrees below the horizontal instead of 40 degrees. The intensity, after decreasing, reaches another high value at 40 degrees, but not quite as great as at 25 degrees. We can give no explanation of the peculiar form of the curve obtained with clear glass, except that it is due to the globe, as a naked arc would seem to have no cause for the uneven curve as shown. The same general variation is shown in a test on the Manhattan lamp by Houston and Kennelly (Fig. 11).

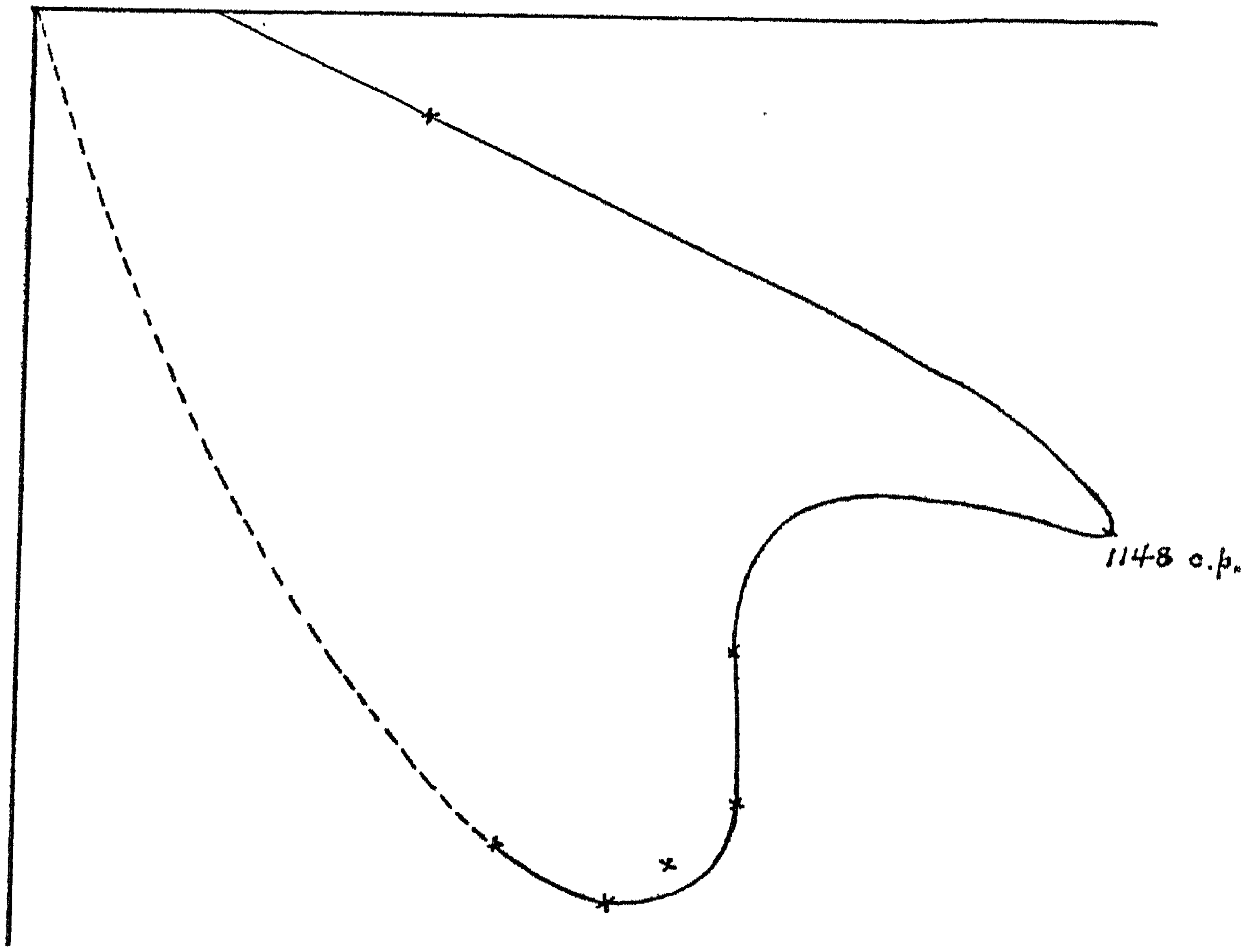


Fig. 11.

The comparative distribution of light in both forms of arc is shown by Table X. The figures given for the open arc are those of Wybauw, Palaz "Industrial Photometry," p. 236.

These are comparative, not absolute values. It will be seen that the enclosed arc gives a wide zone of illumination that is not far from the maximum.

TABLE X.

ANGLE BELOW HORIZONTAL.	ENCLOSED ARC.	OPEN ARC.
0	132	208
10	455	401
20	755	612
25	1000	
30	900	871
40	990	1000
50	838	807
60	548	457
70	465	188

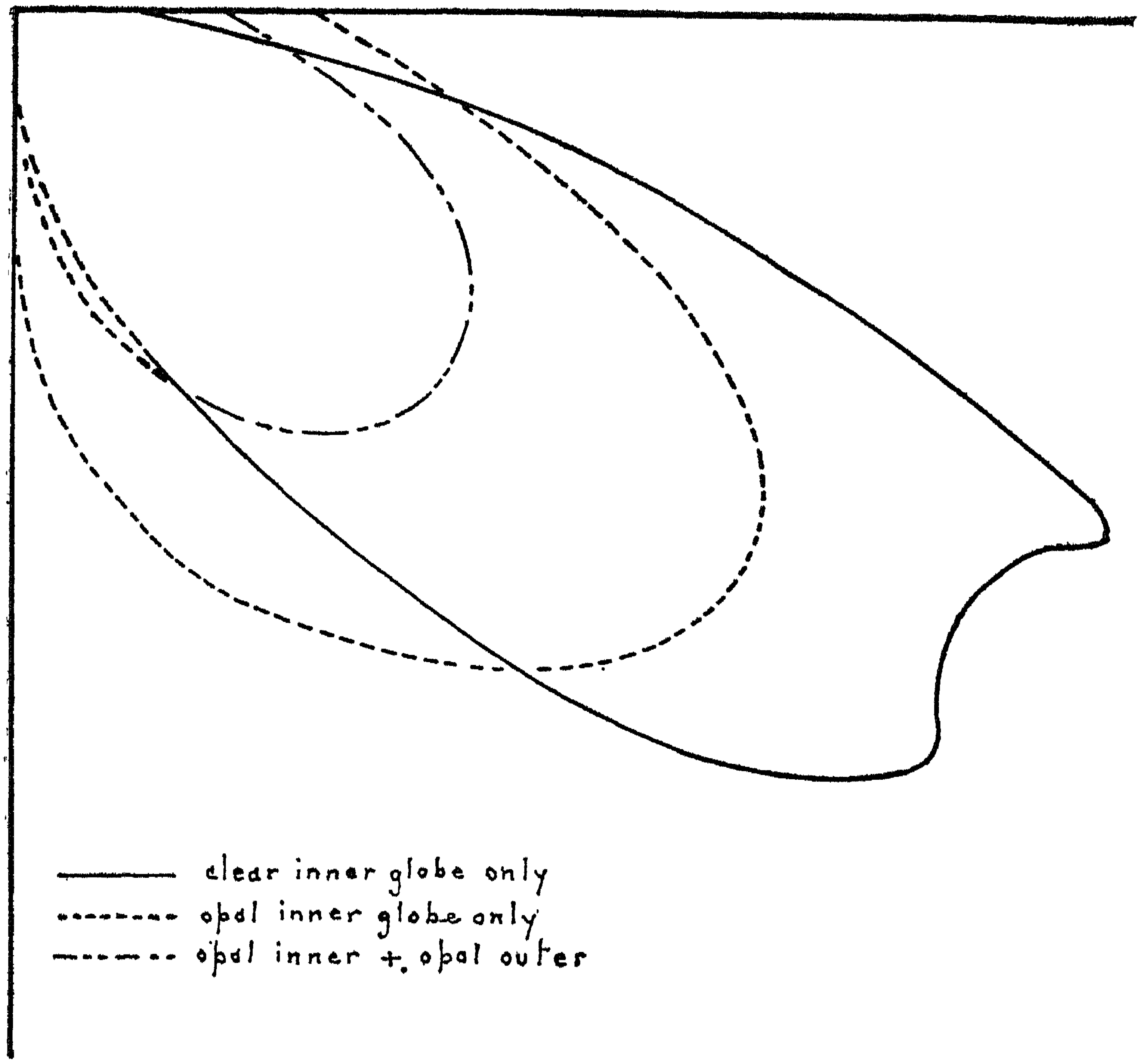


FIG. 12.—Curves from Tables XI and XII.

TABLE XI.

CLEAR INNER GLOBE.

ANGLE FROM HORIZONTAL.	CANDLE POWER.
20 above	89
10 above	82
0	139
10 below	501
20 below	980
25 below	1397
30 below	1300
40 below	1355
50 below	1060
60 below	674
70 below	414
Mean hemi-spherical	850

The actual values with a clear inner globe, obtained by us, are shown in Table XI. Replacing the clear globe with an opal one, we obtained the values given in Table XII. All of these results are shown graphically in Fig. 12.

TABLE XII.

OPAL INNER GLOBE.

ANGLE FROM HORIZONTAL.	CANDLE POWER
20 above	152
10 above	184
0	347
10 below	455
20 below	735
30 below	985
40 below	1050
50 below	969
60 below	855
70 below	734
Mean hemi-spherical	770

With opal globes, the angle of maximum illumination is at 40 degrees, the same as in the open arc, and the reading for 25 degrees is between the values for 20 and 30 degrees. This particular opal globe cut off at least 10% more light than the clear globe.

LIGHT CUT OFF BY OUTER GLOBE.

The amount of light cut off by the outer globe varies for different globes, and even for the same globe, according to the angle, the actual figures found being from 34% to 40% for the same globe, the highest value observed for any globe being 50%. This effect is shown by Table XIII.

TABLE XIII.

Angle below horizontal.	Candle Power. Opal inner globe.	Candle Power. Opal inner and outer globe.
0	184	123
20	844	442
40	1110	568
60	327	180
Mean hemi-spherical	652	380

HOLOPHANE GLOBE.

This is a globe of clear glass, made with vertical grooves inside and horizontal grooves outside. It is from the design of Blondel, and theoretically each groove has a different outline through its section.[1] The object is to get as near a perfect diffusion without loss from absorption as possible. Practically, the globe is made in several zones having the same form of groove throughout a given zone, but different in the next one. The most noticeable change we observed from its use, was in the horizontal diffusion. For a given angle, the readings in different directions around the lamp were very nearly alike, whereas in the ordinary globe these readings were sometimes in as high a ratio as 1 to 3.

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[1] For a full description of the "Holophane Globe" see *Electrical World* Jan. 23, 1897, by E. L. Elliott.

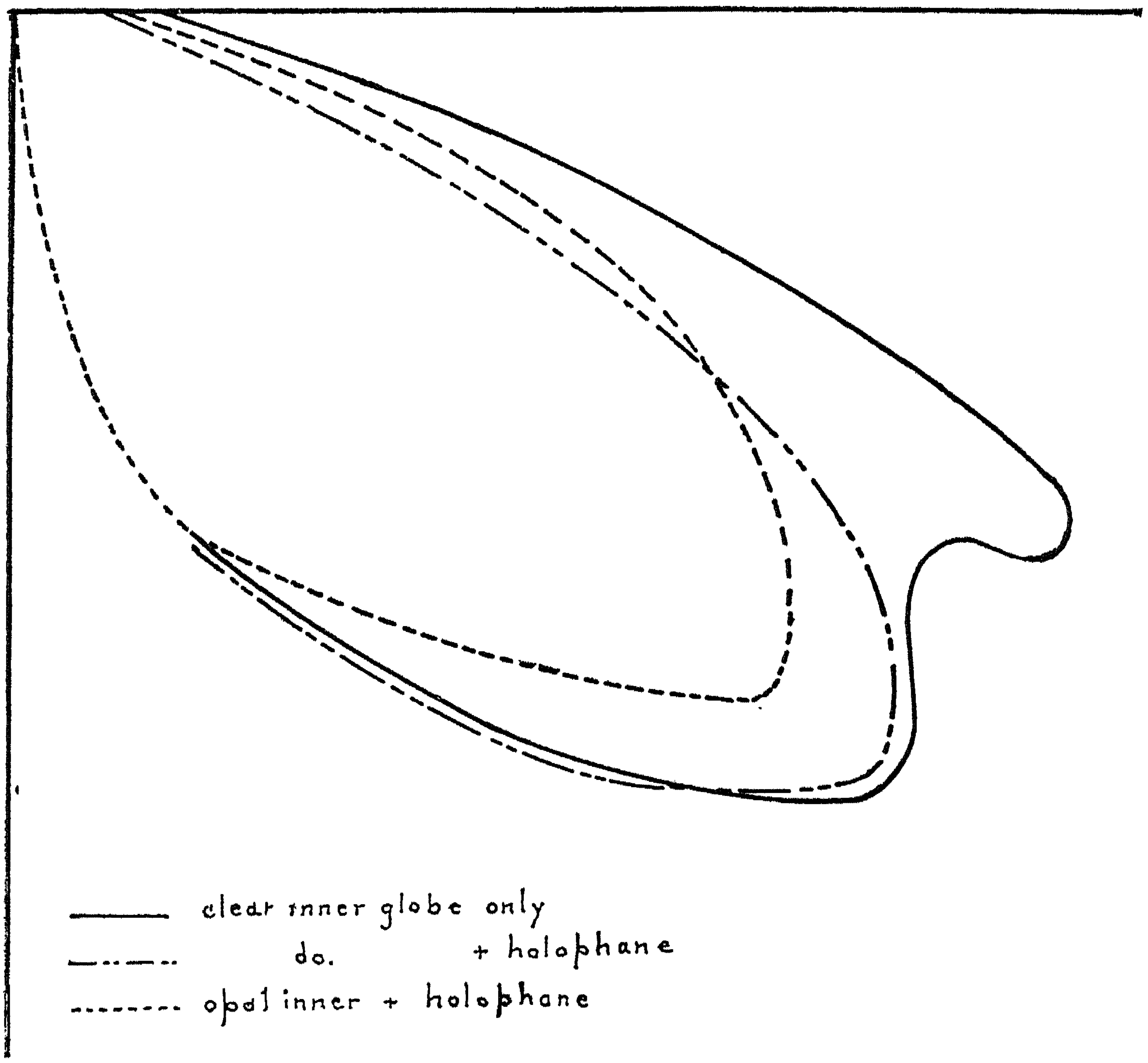


FIG. 13.—Curves for Table XIV.

TABLE XIV.

Angle below horizontal.	Candle Power. Clear inner globe.	Candle Power. Clear globe and holophane.	Candle Power. Opal globe and holophane.
0	171	96	137
10	380	335	252
20	974	496	639
25	1289	783	820
30	1173	1043	950
40	1278	1255	1116
50	1081	1051	915
60	707	852	707
70	600	629	604
Mean hemi-spherical....	854	776	700

The effect of the holophane globe on the distribution is shown by Table XIV and Fig. 13.

The holophane globe, therefore, reduces the light through a clear globe only 9.2%. This seems very small, but a test given in the *Electrical World*, Nov. 10, 1894 (Digest), gives two values, 13% and 9%.

The appearance of the globe to the eye is different from the opal globe; it has a whiter looking light, and appears darker in portions, whereas the opal globe appears of even brightness. A comparison of Figs. 14 and 15 with Figs. 9 and 10 shows this. Really, none of the globes are exactly of the same brightness all over, as, in the development of the negative, only a portion appeared at first, and not the whole area at once.

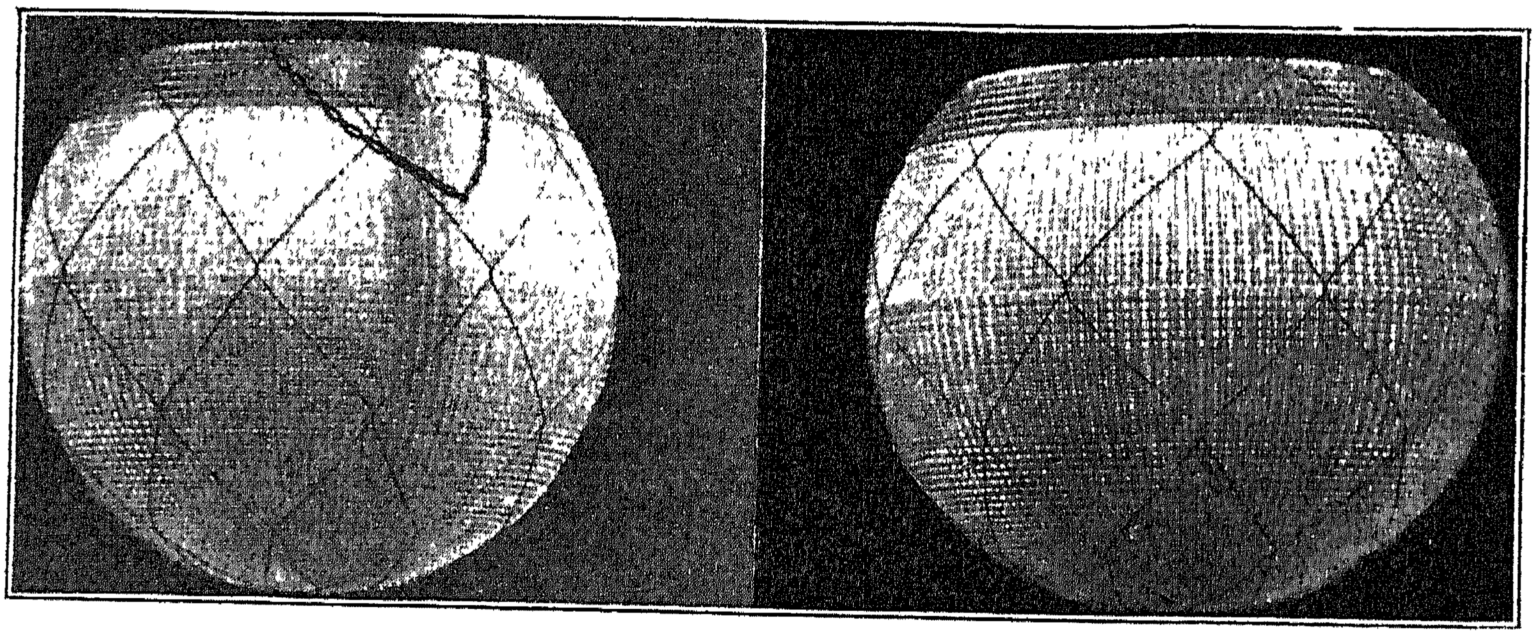


FIG. 14. FIG 15.

The combination of opal and holophane globes given above reduces the mean hemispherical candle-power 18.1% from that given through a clear globe.

Briefly stated, we find:

For two clear glass globes, allowing 5% to 8% absorption for the outer one, the watts per candle are about 0.5, and the candles per watt 1.9;

With opal inner and clear outer, watts per candle 0.56 to 0.60, and candles per watt 1.7 to 1.5;

With both inner and outer opal, watts per candle 0.9 to 1, and candles per watt 1.1 to 1.

Also, the efficiency from the use of the holophane globe was but little less than with the ordinary clear outer globe, some of the latter not appearing to be of good quality.

LIGHT CUT OFF BY DEPOSIT ON INNER GLOBE.

The advantage of long life, obtained by the use of larger diameter or greater length of carbon, is reduced by the fact that the deposit formed on the inner globe cuts off considerable light. In the early part of the run, this is not objectionable; but it would seem advisable not to have a run of over 130 to 140 hours. The deposits all varied in density in the same general ratio, the thickest being at the top, and the bottom being slightly heavier than the middle. The coating was analyzed, and found to contain ferric oxide at the top, carbon dust at the bottom, and silica all over. In some cases it was impossible to clean the globe properly without the use of water. (We are informed that the New York Edison Illuminating Company requires its trimmers to carry extra globes with them, so that if any are still hot, the use of a wet cloth is not required until they can be cooled, the extra globe being substituted.)

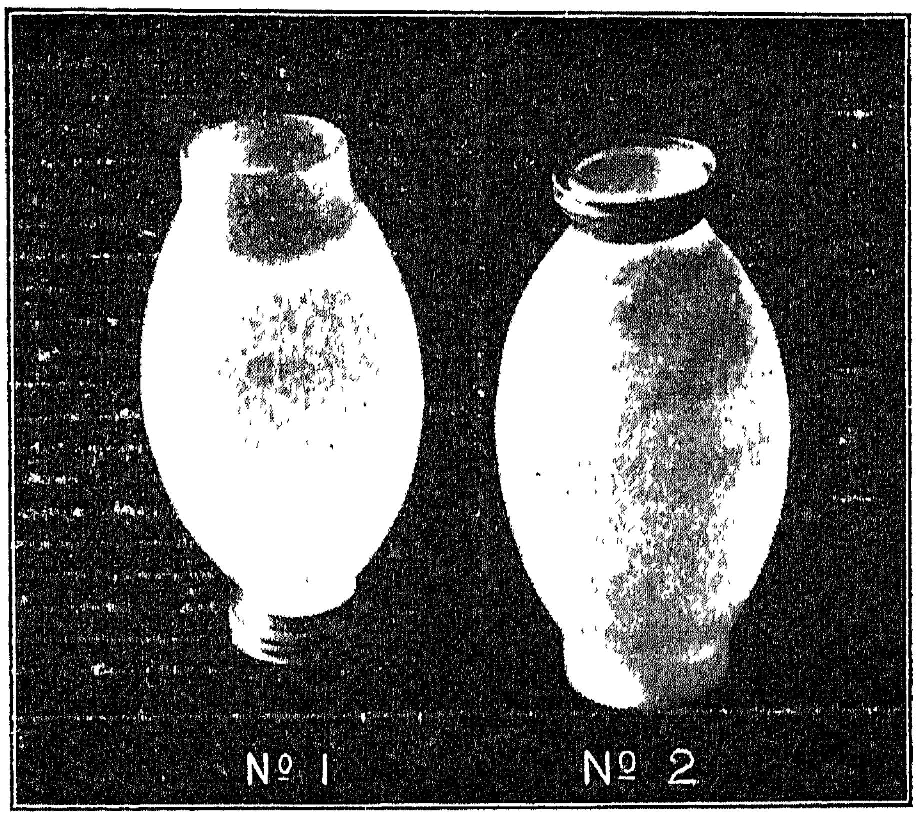


FIG. 16.

The two globes shown in Fig. 16 show a deposit in the case of No. 1, that came from the brass cap, fused into the glass, so that water would not remove it; in the case of No. 2, it is a deposit of carbon, also fused into the glass. The carbon rod had burned to an angle of nearly 45 degrees, and the particles were projected right along this line.

The amount of light cut off by deposits on inner globe is shown by Table XV. As the arc is low down in the globe at the end of the run, the deposit at top has little effect. The middle and bottom are the important parts.

TAPLE XV.

TEST.	TOP OF GLOBE.	MIDDLE.	BOTTOM.
a	30%	20%	20 5%
b	48%	18%	——
c	60%	14%	16%

INSULATION OF LAMP.

The tests made were with the tail-piece as one terminal, and the other parts of the lamp in turn as the other, the terminals of the lamp itself being included; also, between the shell and the lamp terminals. Only lamps Nos. 4, 5 and 7 were completely insulated.

CONCLUSION.

To sum up, we find these advantages of the enclosed arc lamp over the open:

Long life, and consequent saving of carbon, trimming expenses and annoyance from frequent renewals;

Pleasant light, free from hissing and spluttering, and with very little flickering;

Absence from flying dust and sparks, and fireproof qualities resulting from the use of two globes;

Being run on the incandescent circuit, there is no danger from high potentials, and no need of an automatic cut-out;

Simplicity of mechanism, and, consequently, less need of repairs.

DISCUSSION.

THE PRESIDENT:—I would like to ask Dr. Kennelly, who obtained results similar to these, if he has any explanation for them —that the distribution of the light of an enclosed arc lamp has the general form represented in Fig. 11.

DR. KENNELLY:—In regard to the peculiar wing-shaped curve of luminous intensity, when we made the measurements to which the President has just referred, we noticed, of course, that abnormal upper development, which is absent, I believe, in the case of the naked arc, and we assumed at the time that it was due to light reflected from the inner globe upwards to a zone above the positive carbon. In other words, had the inner globe not been there, the entire prominence would have been about 45 degrees below the horizontal plane through the arc; but with the globe in place, many of the rays so transmitted were thrown back again by reflection to an upper zone.

PROF. OWENS:—I would like to ask if the shape of that curve is altered by the peculiar form of the small enclosed globe?

THE PRESIDENT:—I might answer both the statements by saying that it was suspected that the light reflected from the inner globe was the cause of that peculiar distribution, but it was not possible to prove that fact, and the test made with different forms of globe, I believe, did not add anything to the knowledge. Undoubtedly that must be the cause; there would seem to be no other, and possibly changing the form of the inner globe considerably, would prove this to be the cause: but no conclusive test has been made, so far as I know.

MR. L. B. MARKS:—I have no doubt that the form of the small globe influences the shape of the curve. By using a globe that has a very marked curvature, instead of a long flat globe, you get a different candle-power curve; that kink in the curve is not very common in globes that vary in form from the usual shape. I presume that the writers of the paper did not find much difference in the various curves, because the small bulbs which they tested are all very much the same in shape.

I have been very much interested in some parts of this paper, and note on page 427 one of the lamps I designed and some tests made on it. I find that the authors obtained results which are very much the same in some cases as those of former experimenters. Indeed the work of Thomson, and Blondel, and Nichols, and some of my own researches seem to have brought out most of the general results that are given in this paper. I have not had time to examine it very carefully, but I think perhaps a few statements in regards to some of the matters that are presented may be of interest.

On page 430 we have a curve for the relation between voltage across the arc and length of arc. While it is true that this curve is of some value in representing the ratio alluded to, still I hardly think that it would be safe to use a curve of this kind as a basis for any important measurements, because it seems to me that that curve is really one expression of the ratio between the voltage and length of arc of this particular lamp. This ratio varies very greatly in different lamps and in fact even in the same lamp. If you take two cored carbons, for instance, you will find that the ratio varies. You will also find that a figure such as eighty-three volts corresponding to the length of .023 of an inch, as given in Tables VI., may not apply. It may be 20 or 25 per cent. off. Again the ratio will naturally depend on the position of the arc in the bulb. The authors do not give the conditions under which this particular test was made, and without these conditions the tests lose much of their value. If the arc, for instance, is at the top of the bulb, the ratio will be quite different from what it would be if the arc were at the bottom of the bulb. The ratio naturally varies with the amount of air that enters the bulb. We will assume, for instance, that in this lamp which the authors tested, the bulb is air-tight at the time, and the arc is near the top. Then take a condition in which there is a small amount of air entering the bottom, as there is in some of these lamps I presume, and we will assume that the arc instead of being placed at the top is placed near the bottom,—I will venture to say that there will be a difference of perhaps 30 to 35 per cent. between the measurements thus obtained and in the values given in this table. I have made quite a number of tests and I find that it is very difficult to give any particular curve that will come near truly representing this ratio.

The regulation of the lamps is a matter which of course requires a great deal of time to ascertain with absolute certainty. The authors have gone to a great deal of trouble, apparently, to measure the lamps, and I am glad to find they have given us the results of tests which cover a period of months instead of a period of weeks, as is often done.

There is a very interesting point in the paper which the authors have not gone into very fully—perhaps one of the most interesting points in connection with the enclosed arc, and that is the voltage at which an enclosed arc can be safely and steadily run as compared with the voltage of the mains at which such an arc can be run. The nature of their tests is very much the same as those of Professor Thomson, which were recorded in a paper read by him at the convention of the National Electric Light Association at Niagara last month. Their results are however somewhat different than his, and I may say that the results of Professor Thomson, and those given in this paper, are quite different from my own. Take Blondel's measurements made in Paris and you find these are different, and some recent measurements of one of Dr. Nichol's students at Cornell are also different. We have five or six sets of measurements none of which coincide. It would seem to me that it would be extremely valuable for some one to take up that particular part of the table and enlarge upon it. I have no doubt that a thorough study of this one point would bring out a very valuable series of figures of which, at the present time we have no exact knowledge at least as far as published data are concerned. I may say with regard to the remarks made by the authors of the paper, that while they claim that an arc cannot be run steadily below a certain voltage of the mains, which I believe they figure here about ninety-five or so, that this is hardly true, and will depend on conditions. I presume they took the commercial lamps in the market: they used the ordinary bulb, and so on; but if you vary these conditions, that is, change the diameter of your carbon and the amount of current, change the size and perhaps the shape of the bulb and the position of the arc in the bulb, and the nature of the gas checking devices and the quality of the carbon, etc. you will find probably that an arc may be run at a voltage which is very close to that of the mains under some conditions; so that the broad statement that an arc run on mains that are below ninety-five volts is unsteady, would hardly be true; it would depend on conditions, and although the authors, to be sure, confine their measurements to certain commercial lamps, still it is rather misleading to read their statement which apparently refers to all lamps of this type. Then again as the voltage of the mains goes down, it is advisable in order to run an enclosed arc steadily, to operate at slightly lower voltage of the arc. Now the authors have adhered to seventy-eight volts at the arc. They cut out resistance and they lower the voltage of the mains, yet they keep the figure seventy-eight volts at the arc. Under those conditions it was quite natural that the arc should be unsteady at a lower voltage of the mains, and I think that if they had reduced the voltage of the arc when they reduced the voltage of the mains they would have gotten entirely different results. So that the figures here apply to a very narrow set of conditions.

I will not touch on the mechanical points they refer to, although naturally a great deal might be said. I shall try to confine myself as closely as possibie to purely technical points.

On page 435 at the lower part of the page, paragraph 3, the authors say:

"The size of the enclosing globe affects the life, it being less "by a slight amount for a smaller globe. All the other conditions being the same, a lamp having a smaller globe will, during a "given run, have its globe replenished with air from the out"side oftener than if it had a larger globe."

I think that that statement is open to question. Anybody who has experimented with various sizes of enclosing bulbs will have found that there is quite a marked difference in favor of the smaller bulb; that is, with a smaller bulb, under ordinary conditions, the life per inch of carbon is greater. True enough, we do not get the total life of 100 or 150 hours, because there is not sufficient carbon; but the life per inch of carbon consumed is ordinarily greater, in some cases considerably greater, with the smaller bulb. Naturally in changing the size of the bulb, in order to get the best results, it is necessary to change other conditions—to change the gas checking effects for instance whatever they may be. But I believe that generally speaking, the life of a carbon is increased, or the consumption of carbon per unit time is decreased with decrease in the size of the enclosing bulb.

On page 436 we have different forms of gas caps. The gas cap is quite well known now. A few years ago I gave it the name of "gas check." All these forms of gas caps are the same in principle. They consist simply of some chamber device for holding part of the gas formed by the action of the arc, and in that way acting as a check against the ingress of air and egresss of gas.

On page 437 there is a very interesting point which Dr. Crocker alluded to, I believe, as miraculous or important.

The President:—Only peculiar.

Mr. Marks:—Well I admit that at first sight it does appear very peculiar. But the explanation of it seems to be quite simple. In most lamps, as is stated in the paper, the relative life of the positive and negative carbons respectively changes as the arc descends in the bulb. Now here is an apparent exception to the rule. The average ratio is about 1 to 2½ or 3, I believe. My own measurements are a little different from that—perhaps 1 to 4; but they find a case 1 to 10 given on Table 9, page 439. That would be accounted for in several ways. If the voltage of the arc decreases, the ratio naturally increases, and at a certain voltage of the arc and a certain current, it is possible to increase the ratio so greatly as to approach infinity. That is, instead of having a ratio of 1 to 2 or 3, or 1 to 10, you may go up to 1 to 20 or 1 to 50, or more, depending on the voltage of the arc and the current passing at the time.

Regarding the photometric tests, I think we have spent a great deal of time in photometric measurements, and it seems to me that to a certain extent it is time wasted. With the enclosed arc, the character of the light, that is, the quality of the light is quite different from that of the standard adopted in order to make the measurements comparable with others, and I think in some cases the relative measurements of candle power would be meaningless. The authors state very truly that the candle power measurements are not to be relied upon, and they give their reasons. They refer to the difference in value between the standard source of illumination and the arc, and the very marked difference in the color of the light, and point out that the incandescent lamp gives an orange light even when run at its normal voltage. They also refer to the personal error in comparing the lamps. I think perhaps more importance should be attached to this last point than is given here. Different experimenters will get quite different results. In Ithaca we made measurements of the enclosed arcs, and we had ten watchers, and there was a difference of over 50 per cent in the maximum and minimum readings taken at the same angle. Of course this difference is enhanced by the "wandering" of the arc. I am glad to see tests given on the holophane globe. I think this is the first time that any measurements have been given of the relative value of the light with and without such a globe, that is with the enclosed arc lamp. I know that when this question was asked me abroad by Prof. Blondel I had to admit that we had not made any tests in this country.

On page 447 referring to the two bulbs, I hardly know how to account for the deposition of carbon. In case No. 2, it is noted that there is a deposition of carbon at the lower end of the bulb which the authors state was burned into the bulb. If the lamp were operating, as it does normally, it seems to me that this deposition should not occur. I do not know what lamp these bulbs belong to. In fact I do not know the key to the paper. But I have seen bulbs of this particular kind operate in service, and if I am not mistaken there are several thousand of them in New York City, and the bulb which I am referring to, certainly does not give the trouble alluded to here. We have had practically no complaints regarding the burning in of carbon or incrustation of carbon in the lower part of the bulb, and I think that if the authors had operated the lamp under different conditions, or perhaps normal conditions, they would have obtained different results. In other words, nothing but an abnormal condition would account for the incrustation of carbon. Regarding the deposition of brass or some metal in the upper part of the bulb, that is probably due to allowing the arc to play too high in the bulb, probably very close to the gas cap.

The conclusions drawn by the writers seem to cover almost all the advantages of the enclosed arc lamp. There is perhaps one point of some importance which they have neglected to allude to, and that is the ability to run these lamps singly on an incandescent circuit. They refer to that in the paper, but in summing up the advantages of the enclosed arc over the open arc lamp, they have accidentally omitted this point. In many cases, such as small stores, it was necessary formerly to run two lamps in series. Now it is possible to furnish a single lamp to meet the demand. I have a note here, stating that it is to be regretted that the lamps should have been numbered. It would have added very greatly to the paper, I think, to have stated the names of the lamps, giving us the key to the situation. I know that I for one could have discussed the paper impartially and perhaps thrown more light on some of the peculiarities which the authors found. However, I suppose that it was impossible to do this under the circumstances. That is all I have to say regarding the paper, except to add that I am very much pleased to see that the authors have gone into the matter so thoroughly; even if they have not presented many new points they have at least chronicled facts.

Mr. Hollon C. Spaulding:—I wish to add a word of appreciation to the paper on this subject, which has become of daily importance, and to bring out one or two points that I would like to get some more information on. Table No. 8, given on page 437 shows a condition of things rather different from what those of us who are principally on the commercial side have thought to be the fact. I would like to know whether these tests, *a*, *b*, *c*, *d*, and *e*, were made on one lamp, (suggesting also the desirability of knowing what lamp it was,) or whether the different tests were on different lamps; also referring to the statements on page 439 about the possibility of having a shellac coating on the upper carbon rod, and the reference again on page 447 to the carbon rods. It may not be out of place to call attention to the fact that one of the lamps has no carbon rod, and my own experience has been such that I feel very strongly inclined to add to the requisites of successful enclosed arc lamps on page 429, that they should have no carbon rod. Beyond that, and perhaps acknowledging the inadvisability of knowing which lamp was used for each test, it might perhaps be fair to know what carbons were used, or if different kinds were used.

The President:—As to the first point I think that the tests of life on page 437 were on different lamps. In regard to the carbons, they were the ordinary carbons used by the different manufacturers, that is to say, the carbons that were recommended to go with the lamp and supplied with it.

Mr. Marks:—Probably "Electra" carbons.

Mr. Spaulding:—That would be so in the case of the Manhattan.

The President:—I am glad that Mr. Marks was able to give us the benefit of his long experience in discussing this paper, because the paper was taken up from an entirely different standpoint. Absolutely disinterested parties simply took lamps as they found them, the standard lamps on the market, and gave them a pretty thorough, and certainly an impartial test, and it was not intended to go into the general theory of such lamps—the physics of it, you might say, but of the engineering problem to decide what these different lamps will do, and by parties who were not interested in any way in the different lamps. To give the actual names of the different lamps was not considered exactly proper, although it was stated that they were representative types. All the lamps were included, but individualizing was carefully avoided, and I think wisely under the circumstances. Any considerable variations in conditions were of course impossible, because the lamps were simply taken as they were found, and used as recommended by their manufacturers which would seem to be the ordinary condition of practice. There is very little information on this subject available, particularly from disinterested parties, and it was thought that the same information that was useful to us would be useful to others, and I might add that the investigation was originally taken up with the idea of determining for Columbia University whether it would use these lamps, and if so, which ones.

Mr. Steinmetz:—I have been very much interested in this paper, and in the discussion by Mr. Marks. There is however one point which I believe needs some further elucidation, since it may lead to mistakes. That is on page 446. The light efficiency is given there, but it does not state whether the power consumed by the arc alone has been considered or the power consumed by the whole lamp including the rheostat; furthermore whether the lamp was tested when new or after running some time and with a deposit formed on the globe.

The values given there, half a watt per candle, appear at the first view abnormally low—far beyond anything reasonable. But the explanation is that these are not the spherical candle powers. In open arc lamps, it is frequently the custom to measure "hemispherical" candle powers, considering the light thrown upwards as wasted—as may be quite proper—perhaps, where the arc is used for street lighting. The enclosed arc however finds its most useful field in indoor lighting; in competition with the incandescent lamp, and in this case the light, which is thrown upwards, is not lost, but reflected by the ceiling and to a large extent even more useful than the direct light, by giving a diffused illumination which is more valuable than direct illumination. Consequently it would only be proper to measure the spherical candle power, and then with two clear glass globes you would get one watt per candle and with one opal and one clear globe, 1.12 to 1.20 watts, and with two opal globes 1.8 to 2 watts per candle, which means in such case an efficiency fairly close to that of the incandescent lamp. Hence the enclosed arc lamp takes an intermediate position between the open arc and the incandescent lamp in its efficiency. The efficiency is lower than that of the open lamp and higher than that of the incandescent lamp. It shares with the incandescent lamp many valuable features, as the long life, absence of danger from the arc, etc., but it shares the other feature that the light decreases with the time, by the blackening of the globe. It has however the advantage of the incandescent lamp in the latter respect that the quality of light does not change; it remains the same light in color, but decreases in brightness; while in the incandescent lamp the light is yellow and reddish.

I do not think the conclusions drawn in the paper are quite complete, but they are rather one-sided, only the advantages being given. The open arc lamp is undoubtedly a very valuable piece of apparatus. But it has disadvantages, too.

As a conclusion I may then add as disadvantages of the enclosed arc lamp—lower efficiency compared with the open arc, and decrease of light with the time of running.

It would be interesting also to compare it with the incandescent lamp, with which it competes in indoor lighting, and we find then, that the enclosed arc lamp has over the incandescent lamp the advantage of greater efficiency and constancy of the quality of light, but the disadvantage of being a little more complicated in its operation and not quite as handy, and besides, not allowing such extended subdivision of light, having necessarily larger units of light.

MR. CHARLES T. RITTENHOUSE:—On page 432 the authors bring out the point that a saving of about 13 per cent was obtained when using 100 volts compared with 115 volts. Mr. Marks has pointed out that it is not necessary under good conditions to use any external resistance at all.

MR. MARKS :—No, excuse me. I did not say that. I said the voltage might be lower.

MR. RITTENHOUSE :—I understood that the external resistance was not absolutely necessary. Granting that external resistance is necessary, I should like to know, when two lamps are operated in series, whether the gain would be greater than indicated by these results. That is to say, would one lamp tend to regulate another lamp, or is it necessary to use about the same resistance in each of them?

MR. MARKS :—Do you mean when two lamps are operated in series and on a 220 volt circuit?

MR. RITTENHOUSE :—Yes.

MR. MARKS :—Yes, there is a slight gain there, inasmuch as it is possible to operate the lamps at a higher voltage at the arc. As the voltage of the mains goes up it is possible to operate lamps in series as high as 100 volts across the arc, so that there would be a gain in that case.

MR. RITTENHOUSE :—I should like to ask whether it is necessary to have as much external resistance in series as when one lamp is used alone. That is to say, would the resistance in series of the two lamps be double that used in the one lamp.

MR. MARKS :—No ; that would not follow.

CLOSING SESSION. WEDNESDAY, JULY 28th.

THE PRESIDENT :—We have assembled this afternoon in special session to read one paper from this morning's list, and the one assigned for this evening in order to avoid the necessity of holding an evening session. The paper to be considered now is on "Armature Reactions in a Rotary Transformer", by Professor Robert B. Owens, of Lincoln, Nebraska.

A paper presented at the 14th General Meeting of the American Institute of Electrical Engineers, Eliot, Me., July 28th, 1897. President Crocker in the Chair.

ARMATURE REACTIONS IN A ROTARY CONVERTER.

BY ROBERT B. OWENS, D. W. HAWKSWORTH AND H. W. DOUBRAVA.

It was primarily desired to obtain curves showing the instantaneous distribution of induction over the pole faces of a rotary converter for different armature positions and conditions of loading.

In general the method employed to effect this, consisted in measuring the instantaneous electromotive forces under different conditions, generated in a series of small equal evenly spaced coils of fine wire wound over the armature surface. The electromotive forces in these coils in any position were of course proportional to the induction density in that part of pole opposite coil.

The machine experimented upon is of the well known consequent pole type, made by the old United States company. Its output is 3½ K. W. at 110 volts, normal speed 2,400 R. P. M.

Fig. 1, shows two views of machine. At the commutator end are seen three slip rings, connected to commutator, also the contact-maker at the end of shaft. At the pulley end are two contact rings to which the several test coils may in turn be connected. The armature is drum wound with smooth core. The commutator has 54 segments.

The machine originally designed for a continuous current generator, was changed as shown into a 3-phase converter by placing slip rings on the armature shaft and connecting segments 1, 19 and 37 of the commutator respectively to rings 1, 2 and 3. No suitable 3-phase generator being available, it was used only to convert continuous into 3-phase currents. The applied voltage at the brushes was kept exactly at 110 volts, the energy being supplied by a 15 K. W. Edison generator.

Instantaneous electromotive forces were measured by the usual zero method using telephone.

The particular contact maker used may, however, be described. An iron ring was cast in the form indicated in Fig. 2, and attached to a hard rubber disk about ½″ thick: A A^1 are glass wedges and B is a thin steel clock spring placed between them;

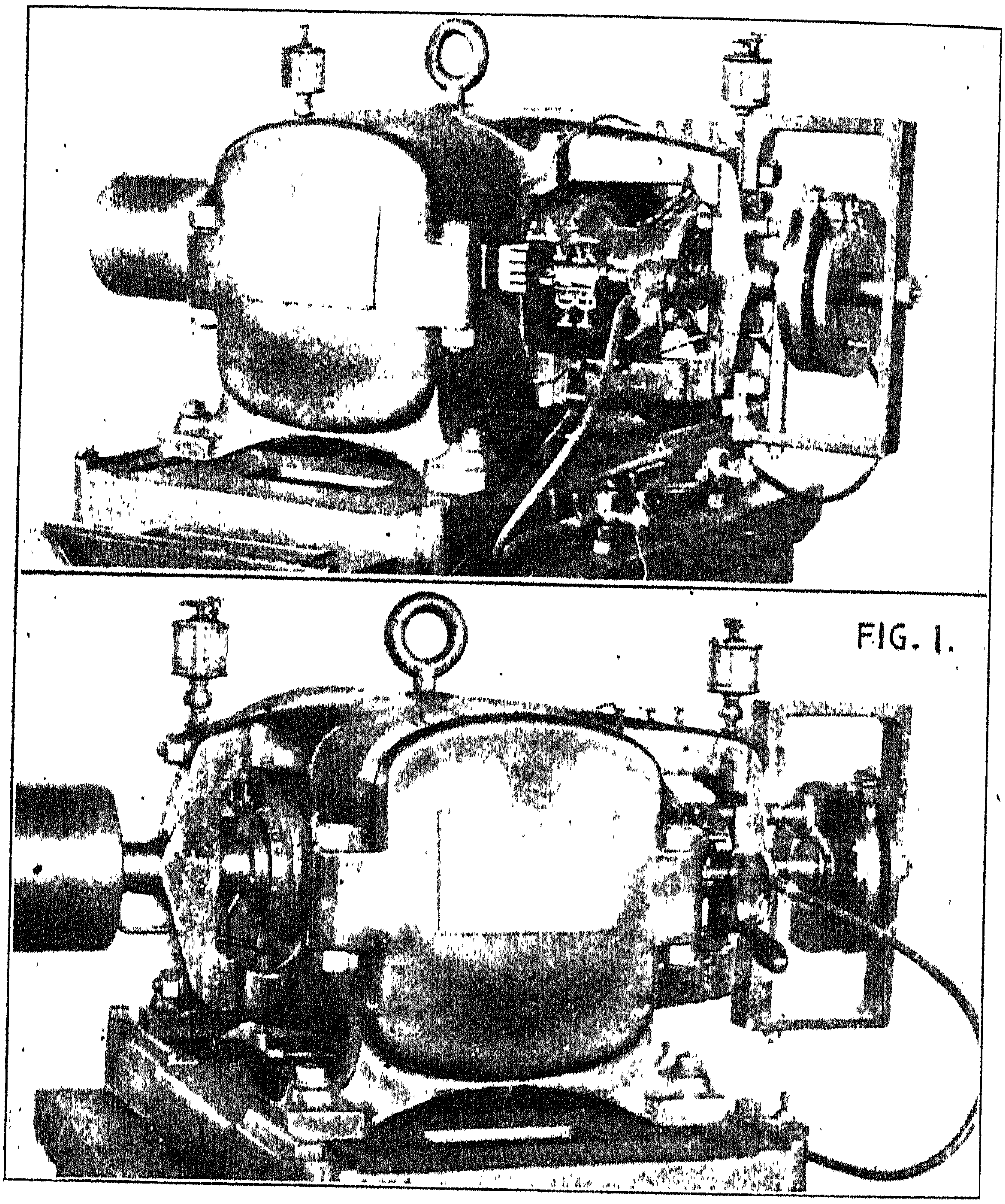


FIG. 1.

O is a screw with insulated head by which the wedges are forced into a wedge shaped slot in the rim and held firmly in place. The metallic strip B is connected to the contact ring E. The glass wedges and strip are ground even with the rim of the cast-iron ring. The contact brush which consists of two thin steel watch springs coming in contact only with polished metal and glass surfaces wears well, and the contact is always clean and good. No difficulty whatever was experienced in reading electromotive forces to less than $\frac{1}{50}$ of a volt.

Since the object desired was to show the instantaneous induction distribution over the pole faces, and the variation in induction density at particular points on the polar surface as the armature and armature currents varied in position and value, the ordinary single or two-brush method of exploring commutator potentials for continuous current machines would evidently be useless. First a single coil of fine wire was wound lengthwise around the armature and the ends connected to the contact rings at pulley end of machine. Fig. 3 represents the relative position of coil and three limbs of secondary circuit of converter; A B is the fine wire coil wound through the point where one contact ring is tapped; I-II, II-III and III-I represent the three limbs of the secondary circuit.

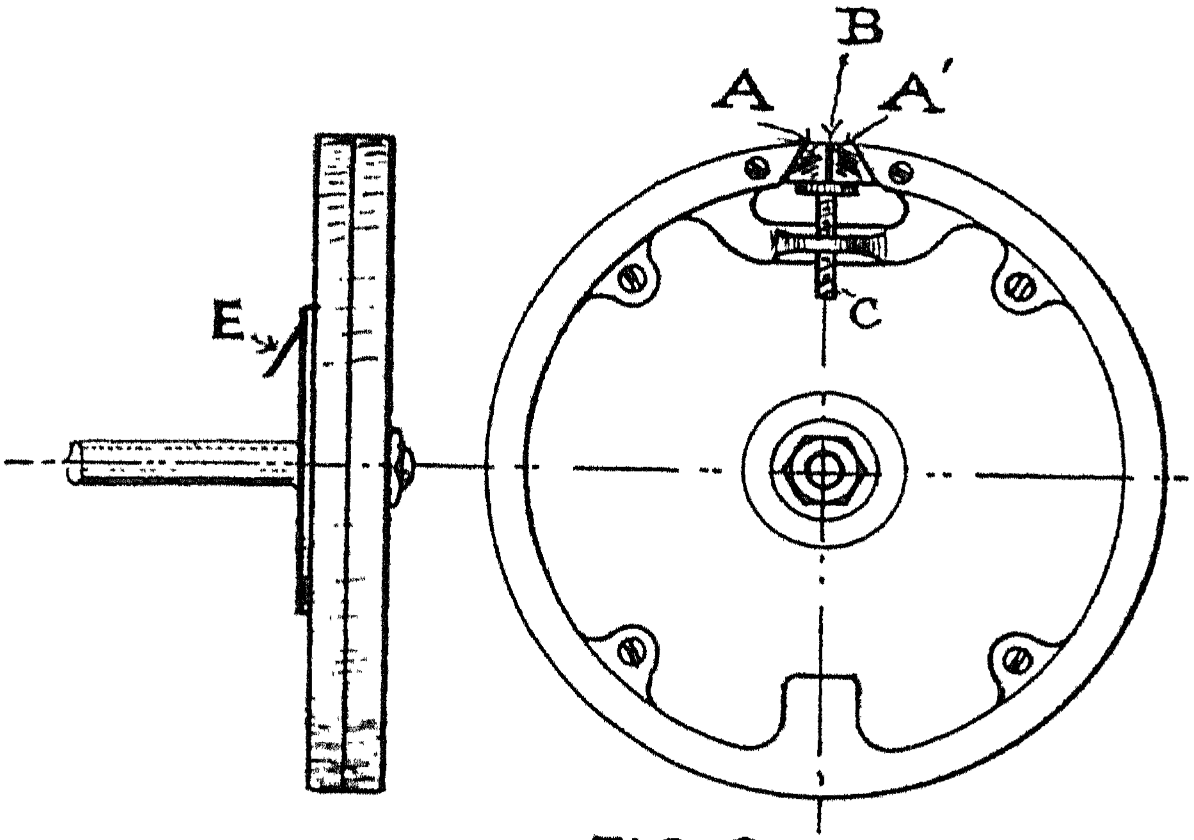


FIG. 2

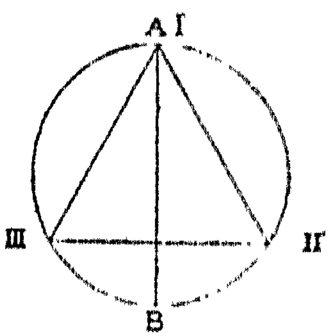


FIG. 3

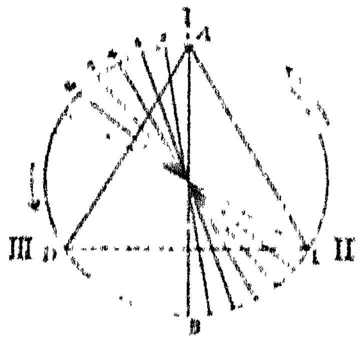


FIG. 4

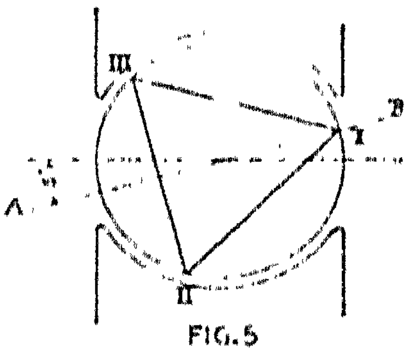


FIG. 5

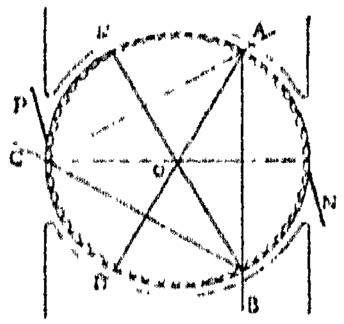
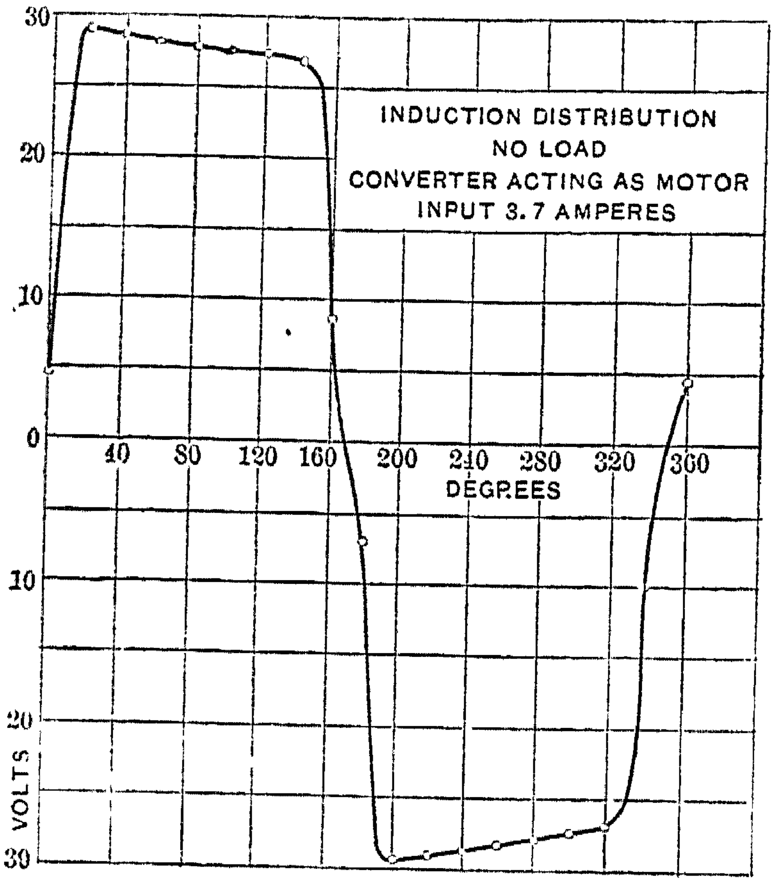


FIG. 6

The machine was first run as a motor with no load and curve

Plate 1 obtained. This shows the induction distribution to be quite uniform over polar surface but slightly shifted in opposite direction to rotation. This would naturally be expected as the armature reactions with so small an armature current wonld be but slight.



.PLATE 1

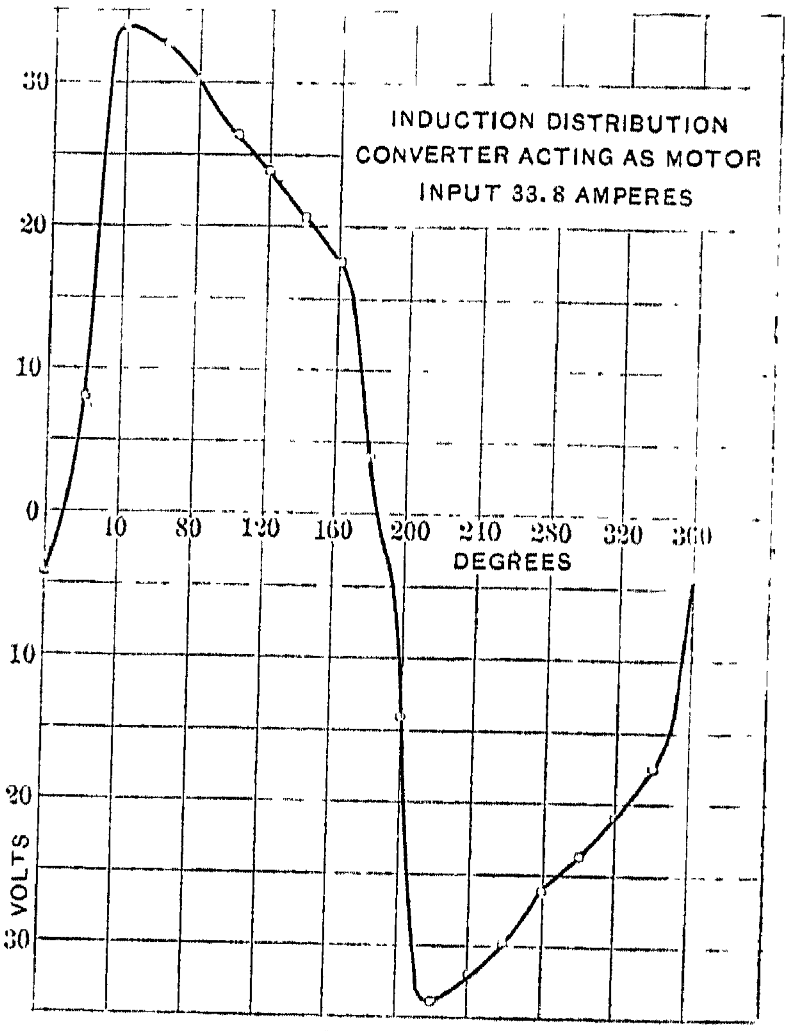


PLATE 2

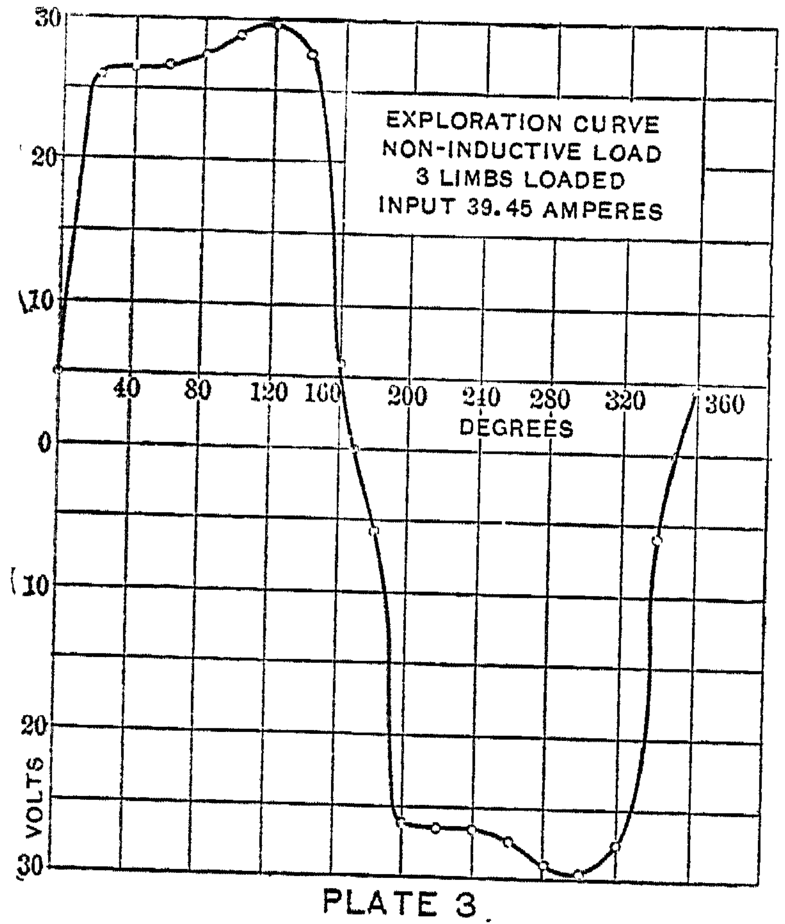


PLATE 3.

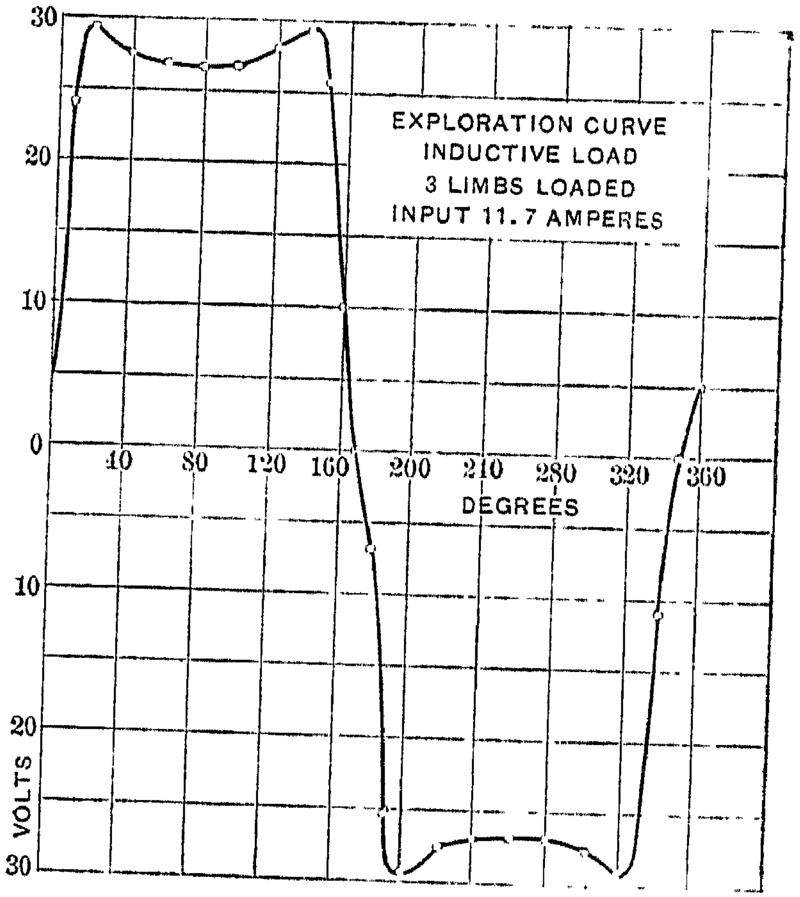


PLATE 4

The machine was again run under steady load as a motor up to about its full capacity, the armature taking 32.6 amperes. In this case the distribution curve shows a very decided distortion of the field as indicated by curve, Plate 2. Both of these curves are exactly like what would have been obtained by the ordinary two brush method of exploring commutator.

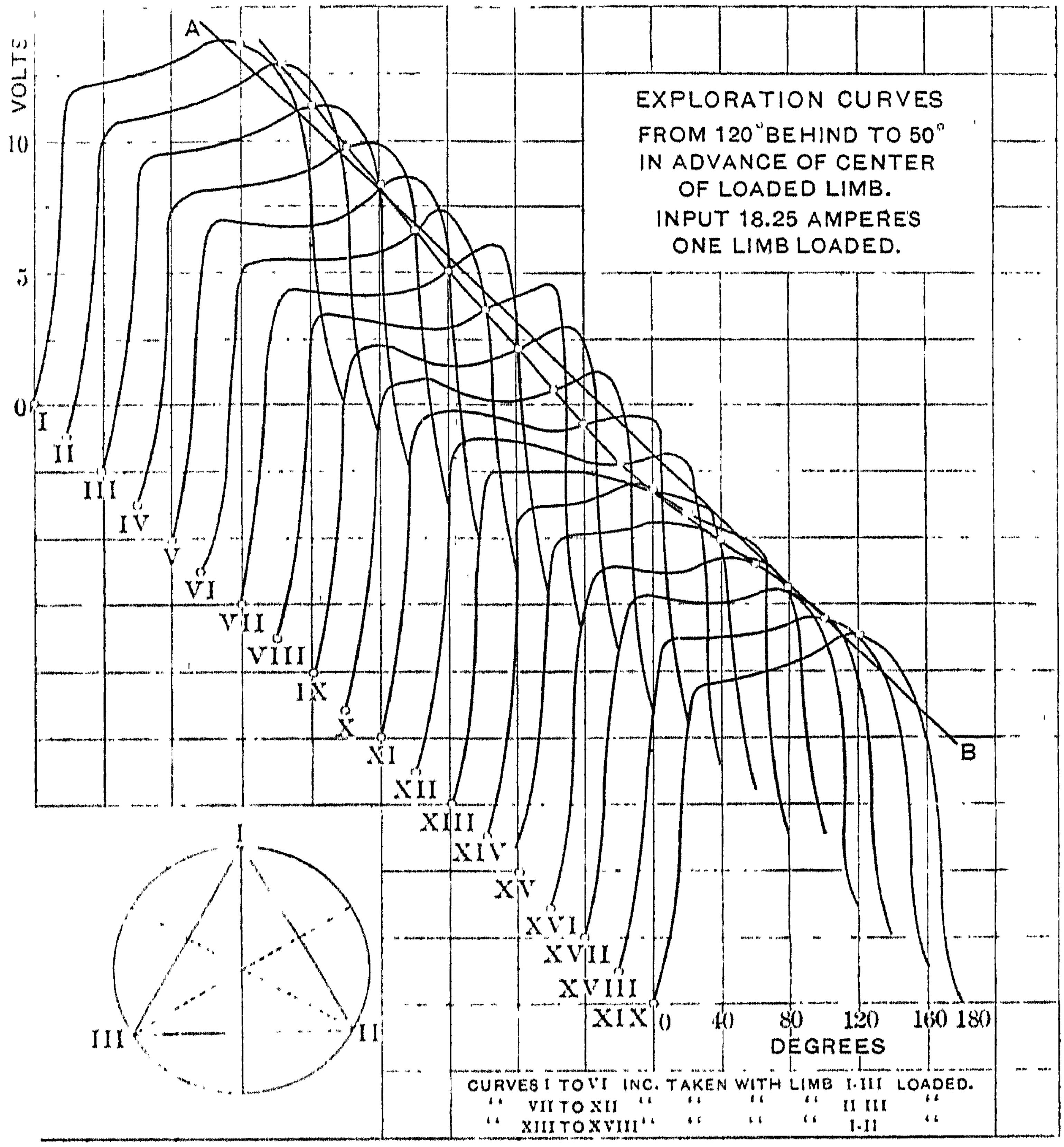


PLATE 5

The machine was next run as a converter, the three limbs being equally loaded with incandescent lamps. The armature took 39.45 amperes. Although in this case the armature current is much larger than when the machine was operated as a motor, no shifting of the brushes was necessary to avoid sparking as was before the case, showing the small reactions in a rotary converter. Curve Plate 3 is the exploration curve from the same test coil for this case, and curve Plate 4 is the exploration curve from test coil when equal inductive loads were put on the three limbs, the armature taking 11.7 amperes. The last two curves must not be confused with curves which show the instantaneous distribution of induction for particular armature positions and loads. They merely show the induction at a fixed angular position from the loaded legs as the armature assumes different angular positions. From a series of such exploration curves the instantaneous induction distribution can, however, be easily obtained as follows: First, we will consider the case of a single limb loaded. It will be seen by an inspection of Fig. 4 that placing test coils 10 degrees apart at points 1, 2, 3, 4, 5, and 6 and taking readings from each separate coil with limbs

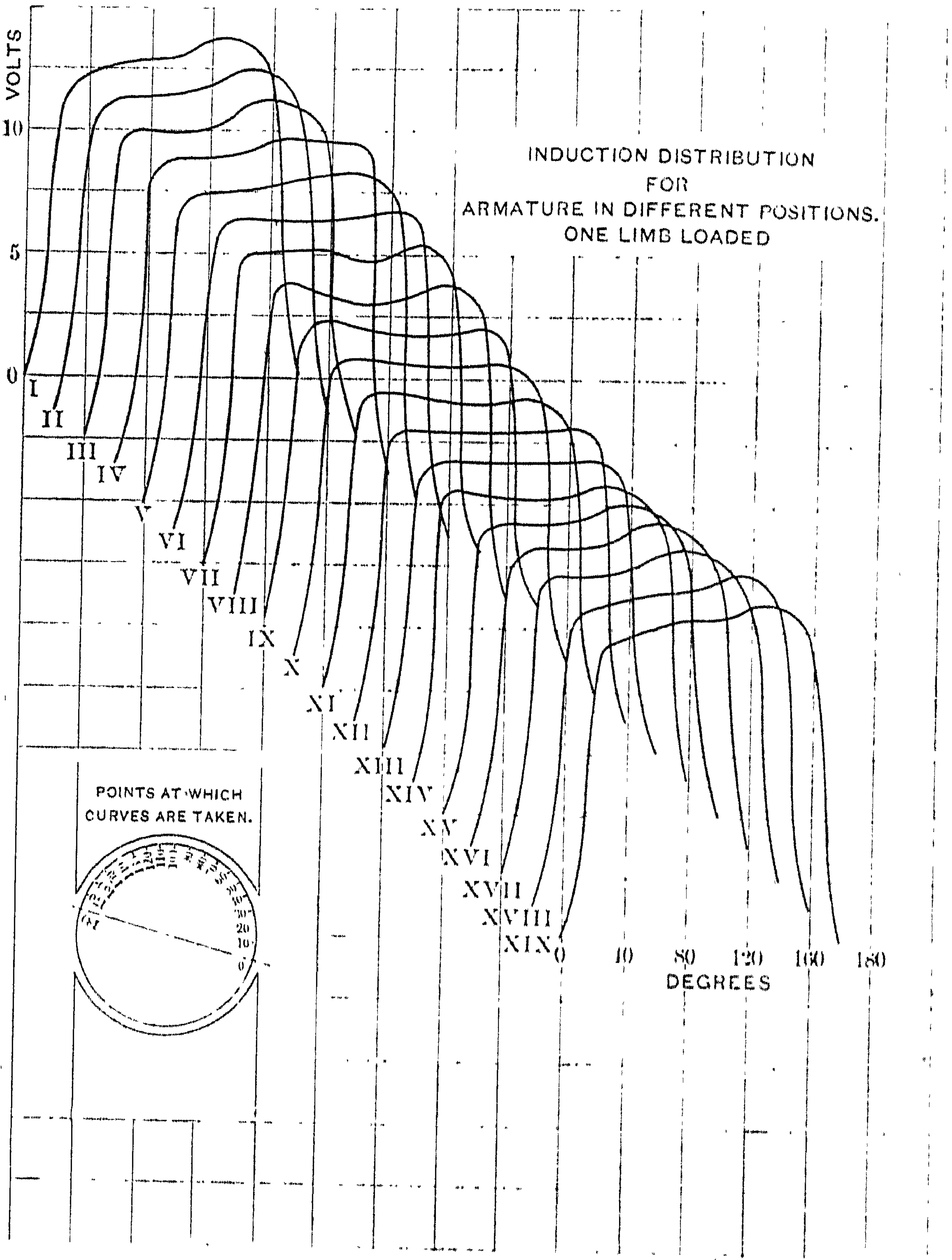


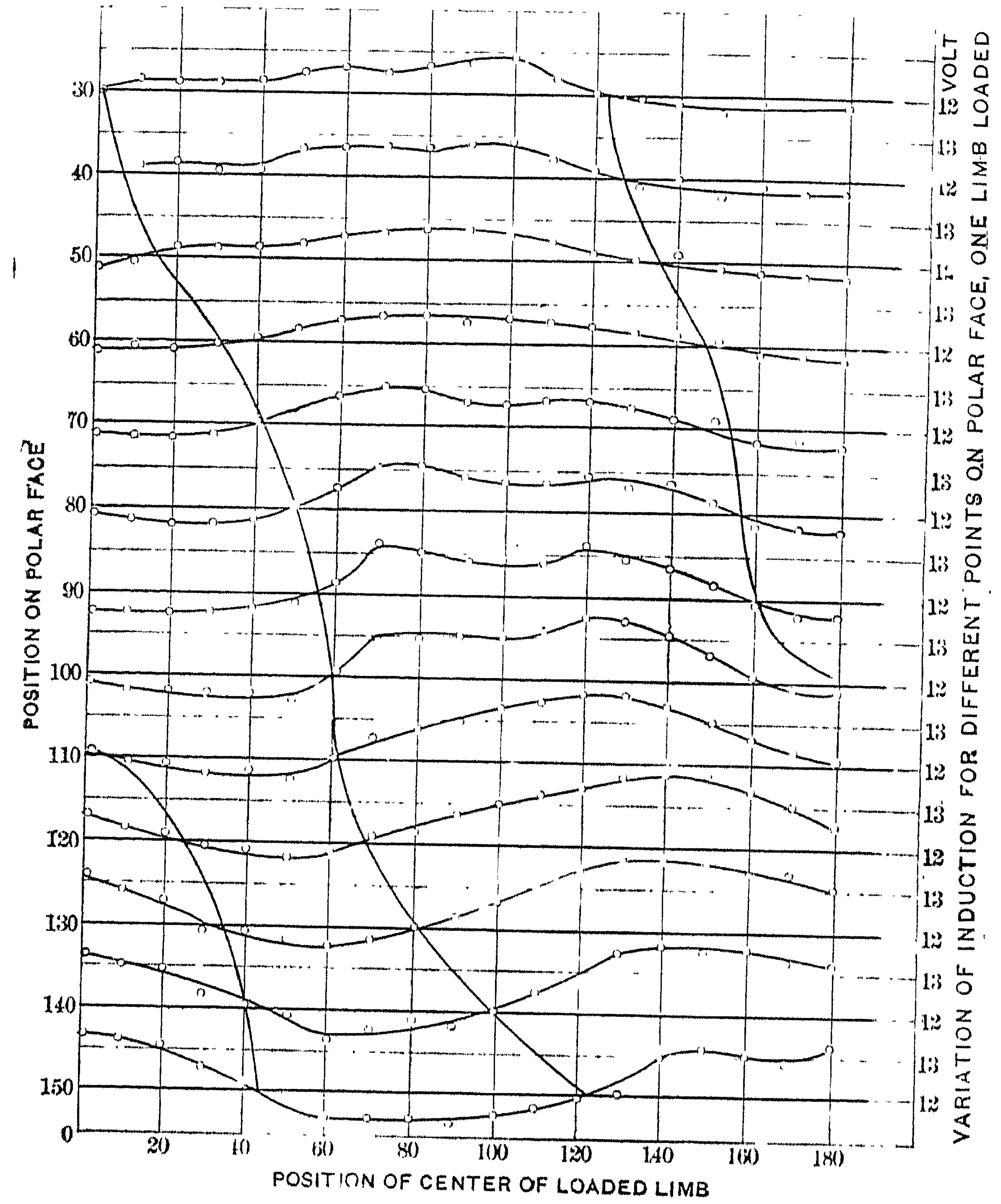
PLATE 6

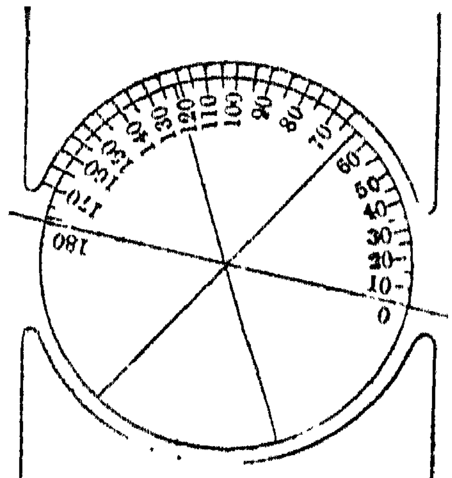
II and III-I loaded separately, is the same as having but b loaded, and coils placed 10 degrees apart entirely around nature, the three armature windings being known to be lly identical. When the limb I-III is loaded, test coil 1 will e induction 60 degrees behind the centre of loaded limb 0 degrees, coil 3, 40 degrees and so on to coil 6. When III is loaded, the curve from coil 1 shows the variation of n at the centre of the loaded limb, coil 2 shows the n of induction 10 degrees in advance of the centre and p to coil 6. When limb I-III is loaded, test coil 1 gives ation of induction 120 degrees behind the centre of the limb, test coil 2, 110 degrees behind and so on up to coil 6. e obtained a series of eighteen curves, showing the instan- induction for every 10 degrees from 120 degrees behind tre of the loaded limb to 50 degrees in advance of the s the armature rotates. The eighteen curves numbered I , are shown on Plate 5. The origin of each curve is 20 degrees to the right and 1¼ volts below that of the ng curve for clearness.

these exploration curves the instantaneous induction tion for particular positions of the armature is easily Suppose that the centre of the loaded limb is on the line nutation, which in all cases is 15 degrees from the point between the pole tips, as shown by line A B in Fig. 5, t the distribution was desired for the limb in this position. e of commutation is taken as reference line. It will be reference to Fig. 4 that taking the zero point of curve s the induction at the point where the centre of the loaded at zero degrees; then if the reading is taken at 10 degrees e VIII, the amount of induction for 10 degrees in advance centre of the limb, in same position, is obtained. The n for 10 degrees further will be represented by the read- 20 degrees on curve IX and so on.

eries of readings for curves, Plate 6, were obtained in this , and show the instantaneous distribution of induction pole faces with one limb loaded in different angular po-

urse, the same curves might have been obtained directly, suring successively the electromotive force in each of a f test coils evenly spaced for one particular position of the limb or armature, but the above indirect method is easier pulation.

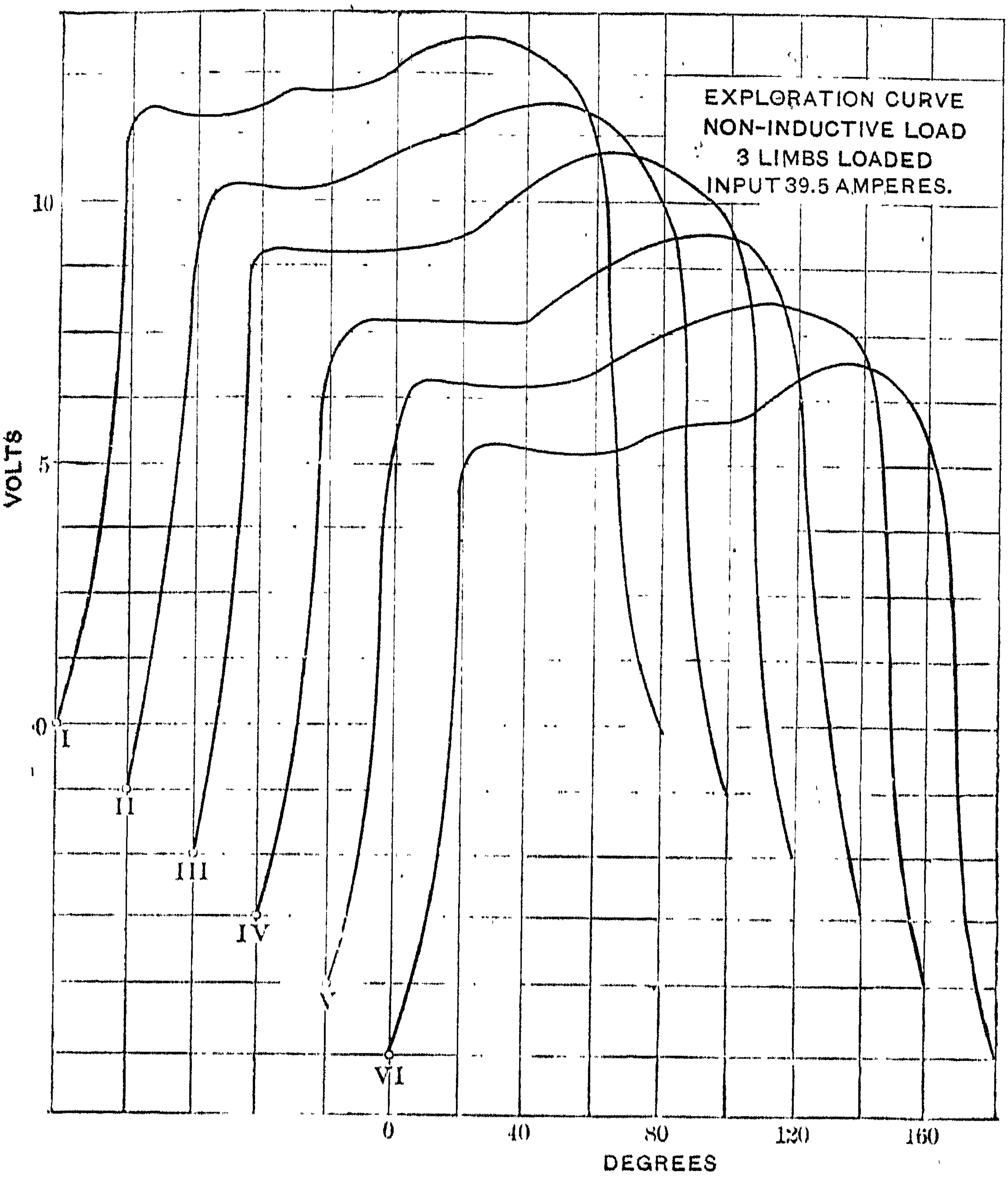




POINTS AT WHICH CURVES ARE TAKEN

PLATE 7

The curves, Plate 7, show the variation of induction through particular points in the polar face as the loaded limb assumes different positions. These curves are obtained directly from the


EXPLORATION CURVE
NON-INDUCTIVE LOAD
3 LIMBS LOADED
INPUT 39.5 AMPERES.
VOLTS
10
5
0
I
II
III
IV
V
VI
0
40
80
120
160
DEGREES

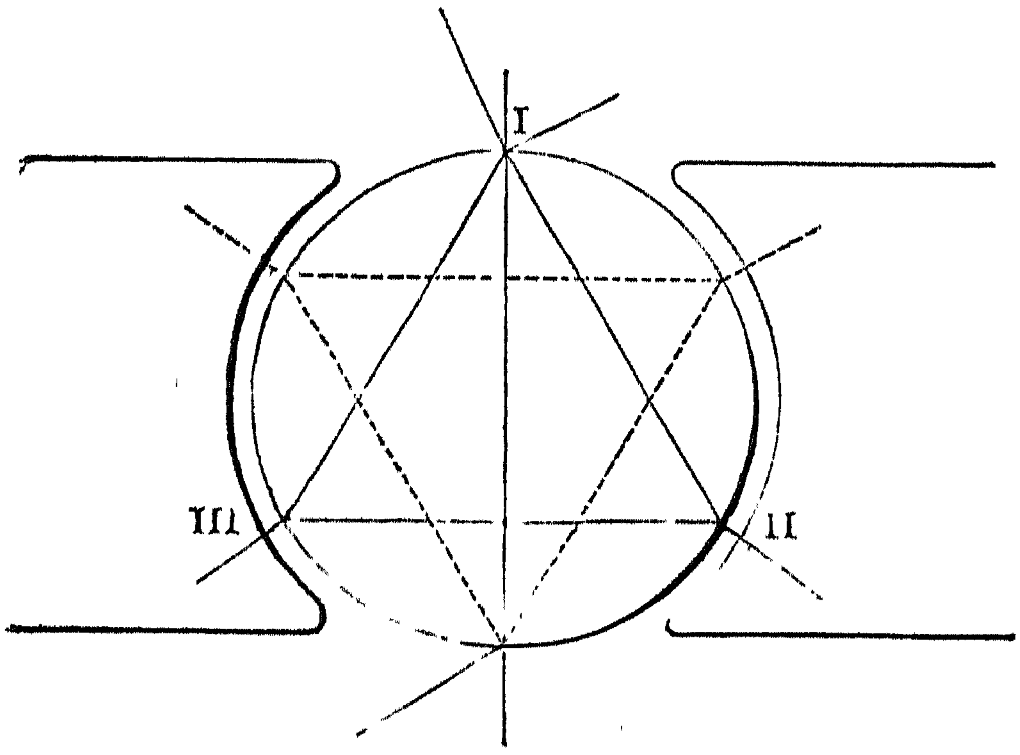

I
II
III

PLATE 8

curves, Plate 5. Suppose it is desired to draw a curve representing the variation of induction at 140 degrees from the zero point. Connect the points where a vertical through the 140 degree point of each curve intersects the curve. The new curve so found, when compared with the right line A B, drawn through points representing 140 degrees and 12 volts for each curve, shows the variation above or below the induction corresponding to 12 volts.

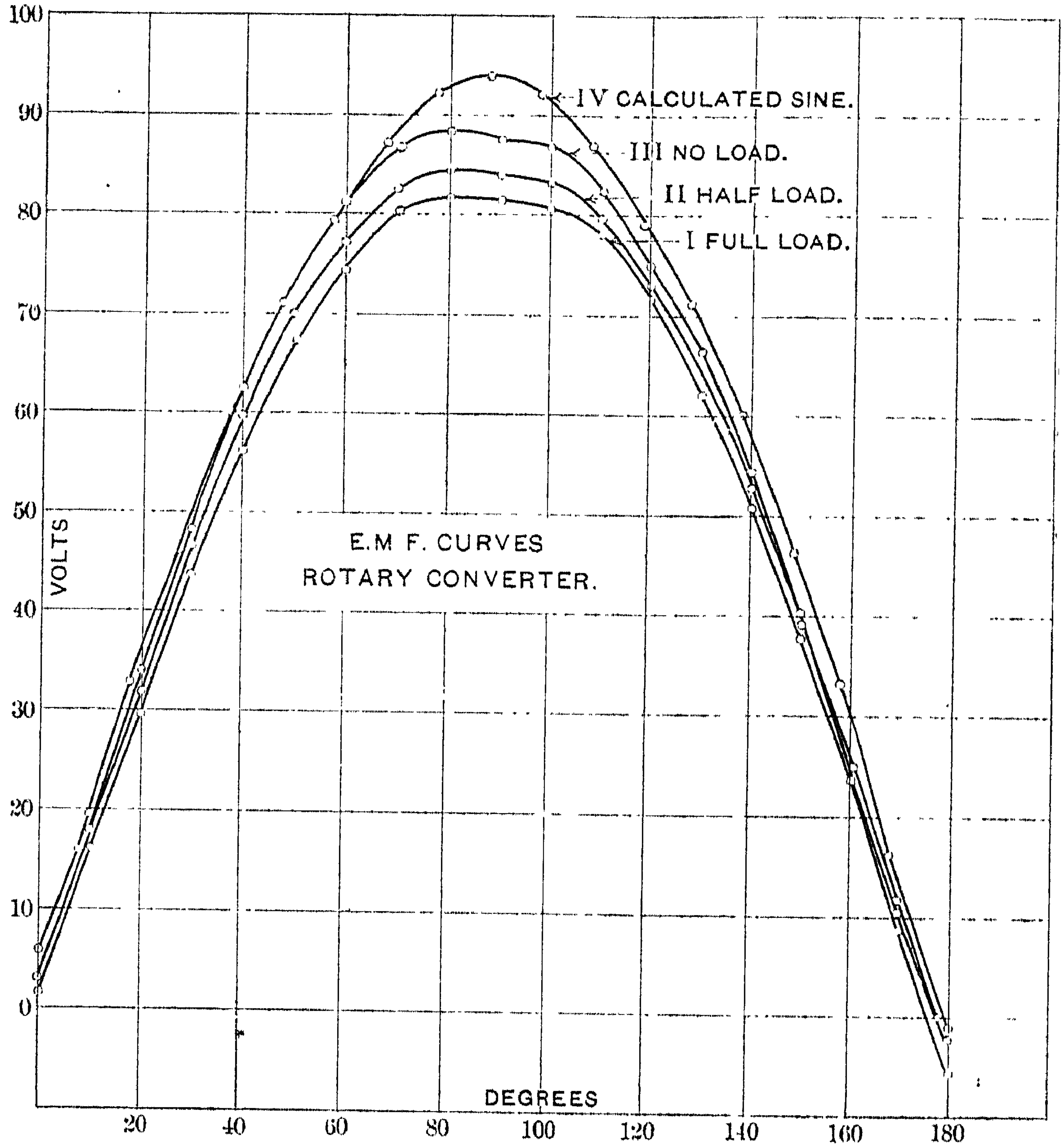


PLATE 9

Taking points from 30 degrees to 150 degrees, inclusive, and changing the axes, gives the series of curves, Plate 7. It will be noted, that the variation of induction at some points is greater than at others, and that the waves of variation differ in phase as of course would be expected. Connecting the points where these curves cross the 12-volt line shows the variation of induction at successive points in time and amount very nicely.

The exploration curves, Plate 8, were taken with all three limbs equally loaded with incandescent lamps. When one limb is loaded, any particular distribution of induction occurs twice in every revolution of the armature, but with three limbs loaded, this happens six times per revolution. In Plate 8, curve VI is exactly similar to curve I, and referring to Fig. 6, it will be seen that the distribution of currents in the armature will be the same when A B and C are either at N or P. The curves showing instantaneous distribution of induction with armature position can be obtained from the exploration curves in Plate 8 in the same way that curves, Plate 6, were obtained from curves, Plate 5.

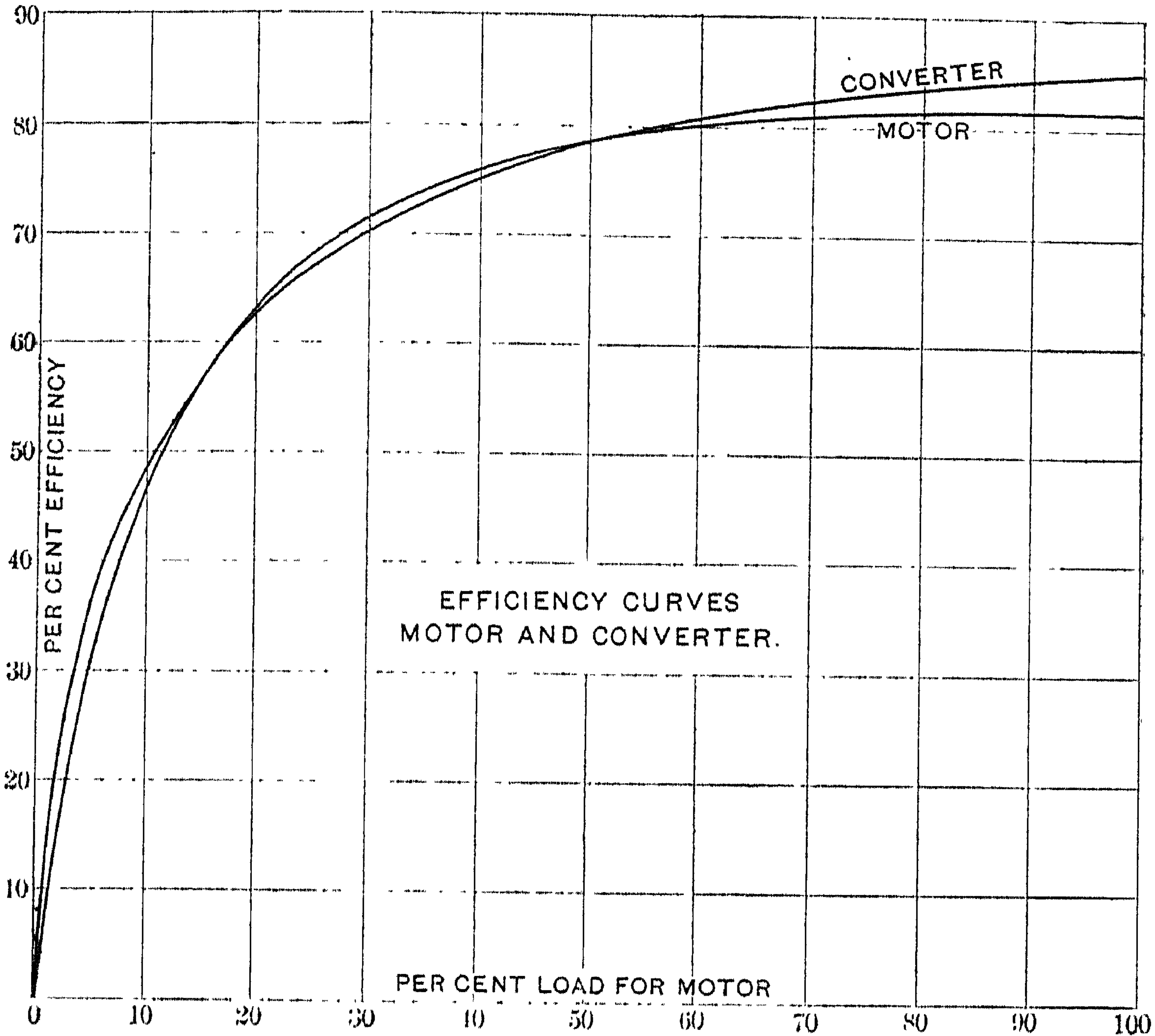


PLATE 10

The shape of the electromotive force curves taken from a rotary converter depends on the induction distribution. If the lines of force through the poles, air gap, and armature were uniform and parallel, the electromotive force in each turn of wire on the armature would be sinusoidal, and the electromotive force as measured between any leg being the sum of sine waves would also be sinusoidal, but the electromotive force curve we actually get is the sum of a series of electromotive force curves similar to curves Plate 5, differing in phase by the conductor angle. On Plate 9 are shown electromotive force curves between legs for different loads. Curve I is for full load, curve II for half load and curve III for no load. Curve IV is a sine wave whose R. M. S. value is 67.4 volts. Plate 10 shows the efficiency curves for the machine as a motor and as a converter. If the load on the machine as a converter had been increased until the losses equalled the losses of the motor at full load, then the ratio of the two outputs would be the relative capacities of the same machine working in the two ways. It is regretted that limited time prevented a more complete experimental study of this machine, but it is hoped that some of the results are not without interest. A detailed study of a more modern machine will be reported later.

Of course the results as found, agree with what might have been anticipated and are probably not new to the engineers of some of our manufacturing concerns, but as the experiments of a company's engineers form part of the company assets, they do not always find their way into engineering literature.

DISCUSSION.

THE PRESIDENT:—The paper gives the result of interesting experiments on this type of machine which is now coming into quite general use. It has some peculiar properties. One point that I think is interesting is the fact that the converter efficiency coincides with the motor efficiency, but is slightly greater at nearly full load. It would seem to me that it ought to be even higher than it is in respect to the motor efficiency.

PROF. OWENS:—The converter was not worked to its full capacity. The machine was only loaded to the capacity as a motor but not as a converter.

THE PRESIDENT:—If carried further, the converter efficiency would have arisen considerably above that of the motor.

PROF. GOLDSBOROUGH:—I have found in looking at Plate 6 of Prof. Owens' paper a most interesting set of curves. To me the problem of the rotary converter is a very attractive one, and this set of curves presents a great deal that is of interest, in view of the fact that it gives us the first series of curves ever published showing the variation of the distribution of the flux over the air-gap of an alternator for various instantaneous values of the armature current.[1]

These curves illustrate very nicely the character of the armature reaction which takes place, and I think also give an insight to certain of the current reactions which take place in the armature conductors, and which I do not believe are mentioned in the paper. In a direct current motor-generator of similar character, that is in a machine having a double armature winding, and which, we will say, transforms current from 100 to 200 volts, the currents of the motor part flow in an opposite direction to the currents of the generator part of the machine. That is, providing the machine is of 100 per cent. efficiency, and that the resistance of the receiver circuit is negligible, the armature reaction of the motor part will be entirely annulled by that of the generator part, and there will be no distortion of the air-gap field due to the currents flowing in the armature. Now, as there is but one winding on the armature of a rotary converter, the alternating currents flow in the same winding, but in an opposite direction to the direct currents, and therefore the current density in the conductors of the armature must vary considerably from time to time. To indicate possibly a little more clearly the point which I wish to make, I will draw a figure here on the board. (Fig. 7.) Suppose we consider for a moment a rotary converter, which has an efficiency of from 60 to 65 per cent. This is a low efficiency for a rotary converter, but such a machine would produce an alternating current in the receiver circuit having a maximum value equal approximately to the value of the direct current supplied the machine. In other words, if (N) represents one pole of a bipolar machine, (S), the other, and O. T., its Gramme ring armature, we can take a base line A, to represent the zero line of current, and another line B., to represent the value of the direct current flowing into the armature at +. Then, supposing that we have simply a single phase secondary alternating current, which we can obtain from the bipolar, direct current armature if it is tapped at two diametrically opposite points 1, 7, we can let the curve C, represent the instantaneous value of this current, and it will flow from the collector brush +. Now, with this machine, if I mis-

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[1] In the spring of 1895 two of my students, Messrs. Crane and Reeves, made a determination of a similar set of curves, taking them from a six-pole single phase rotary converter.

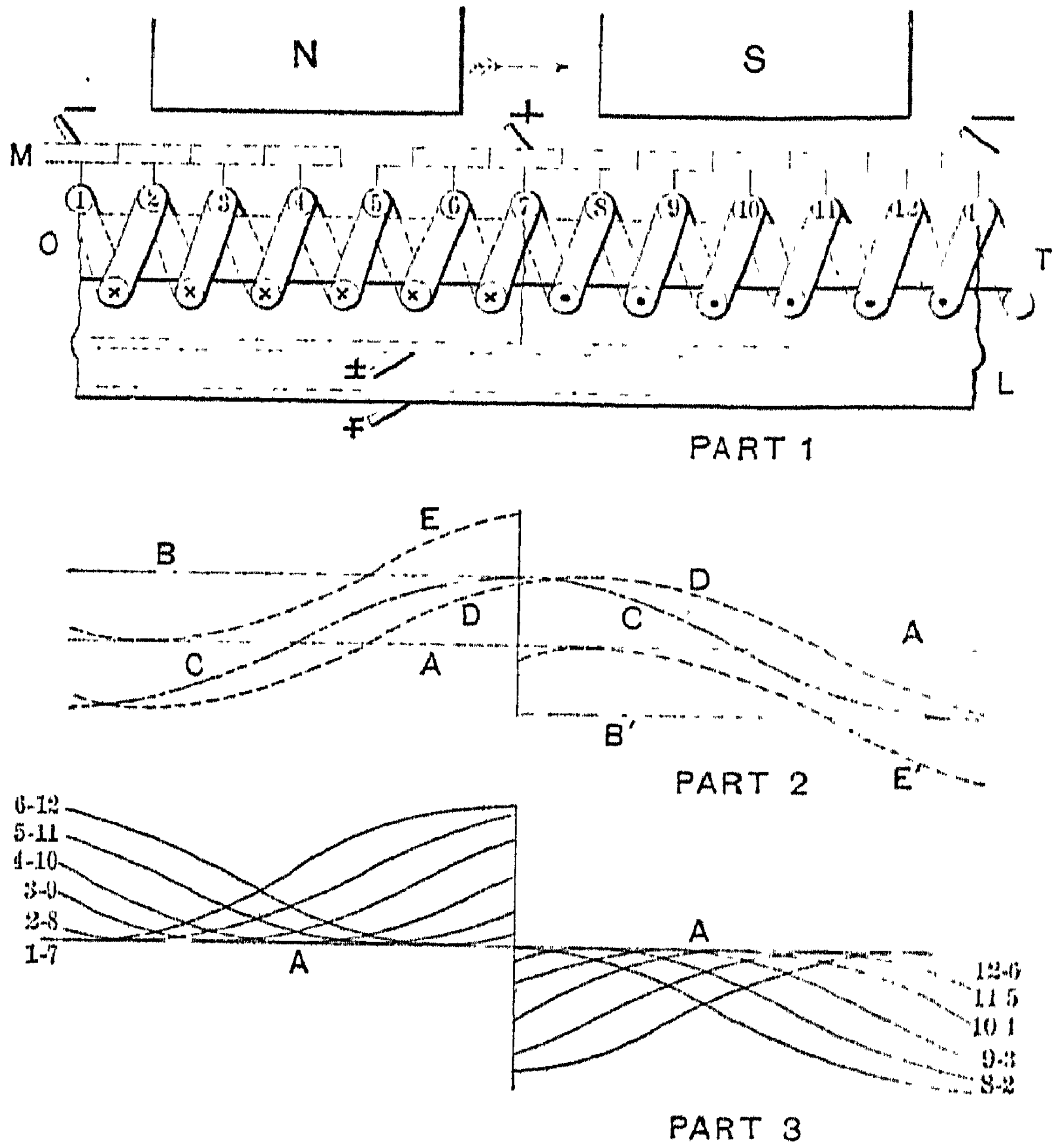

FIG. 7.

Keep the poles and curves stationary and move the conductors; then the current in any conductor in any position is determined by projecting it upon its current intensity curve of Part 3. The dots and crosses on the conductors show direction of direct current.

take not, with the brushes + and — resting on the commutator, M, as shown, when the alternating current rises to a maximum, which it does with the armature in the given position, the alternating current will be automatically drawn straight through from the direct current, and therefore at this instant of time there will be absolutely no current flowing through the conductors on the armature of the machine. This represents a particular case, and one which we could only have when we should design a machine with relatively low commercial efficiency. It could be brought about by increasing the iron losses to a considerable extent, or by loading it mechanically by means of a pulley and belt, so that the electrical output of the machine would be low relatively to the input. Now the curves of Plate 6, I think, bear out this condition, in a somewhat more complex case; in one in fact in which the efficiency of the machine is somewhat higher than in the machine which I have assumed. To look at the matter however a little more closely before going on, I will consider that we have in Fig. 7, a section of the armature of the machine. We have here, we will say, a conductor 7, which connects with the commutator segment right under the + brush. To right and left of this we have conductors in this way, each one of which is connected with a commutator bar, and wound around the Gramme ring. We will consider that currents flowing toward us in the conductors on the upper surface are positive currents. Below the Gramme ring, we can draw the collector rings from which the alternating current is taken, and suppose, for instance, that I connect the upper alternating current collector ring to bar 7 of the armature by a wire, and the lower one to bar 1. Rotation may be considered in the direction of the arrow, for instance. Suppose we designate the conductor which is on the right side of the bar 7 that is connected to the collector ring, by the figure 8, and the conductor on the left side by the figure 6. The alternating current, which we have represented by the sinusoidal curve C, will have the same intensity in both conductor 8, and conductor 6, and we may consider now the combination of the alternating and the direct currents in the armature and the actual value of current intensity which results in the conductors at successive intervals of time. When conductor 8 is over on the left side of the centre line, for instance anywhere between position 1 and 7, it will carry a current which is equal to the value of the curve B, plus the ordinate of the curve D, corresponding to the assumed position of conductor 8, or to the ordinate of the curve E. This means that if we start from conductor 5, since at this point the alternating current in conductor 8 is zero, the value of the alternating current will rise up above the straight line B, until it reaches the central position at + in the centre; then suddenly, when the maximum value of the alternating current is the same as the direct current in the armature, the current will entirely disappear from all the armature conductors. It will begin to rise again in conductor 8, but in a negative direction as soon as conductor 8 passes under the + brush. Curve E E′ is then a curve which shows the instantaneous values of the currents in conductor 8. Of course, in the case of conductor 9 an entirely different curve is required to represent the variations of the current in this conductor owing to its different position relatively to conductor 7. Now conductor 6 will have a current intensity curve which is entirely analogous to curve E E′ except that it is reversed in position as shown in Fig. 7, Part 3. The current intensity curves of all the other conductors are also considered separately in Part 3. The curves show to some extent the character of the current changes and the current intensity modifications which take place in the conductors on the surface of the armature.

Now referring to the curves of Plate 6, I think we can trace some of the points which I have mentioned in connection with this hypothetical machine very readily. For instance if you will note the position of curve 1 of Plate 6 you see that it is a curve which is high on the right hand side, and you will notice further that the curve 1 has a greater altitude on the right side than the other curves. It indicates therefore that at that instant of time the alternating current in the coils of the armature was zero and that therefore the distribution of the magnetism over the face of the air-gap is the same as that represented, or analogous to that represented in Plate 2, which shows the distribution of flux over the air-gap when the alternating current is zero; that is Plate 2 represents an exploration curve taken when there was no excitation at all of the alternating current circuit. In other words it represents a loaded exploration curve of the machine, time being counted from left to right. It is analogous to curve 1 of Plate 6, where, as determined by comparison with Fig. 4, and the statements made at the middle of page 463, time is counted from right to left. Now the alternating current, as soon as a movement takes place to either side of the zero position begins to rise. It rises until finally, at the position marked 6 or at the position marked 12, the alternating current reaction equalizes that of the direct current. At those points therefore you have just sufficient alternating current reaction to compensate for that of the direct current, and you get a perfectly symmetrical field in the machine. I would not say that at this point the currents flowing in all the armature conductors have a zero value, as the conditions are not such as to produce that result. Nevertheless it indicates a point where the reaction of the current flowing in the armature is lost for the moment. Now for points extending between curves 6 and 12 of the series of loops of Plate 6, there is a distortion of this curve in the opposite direction. That is, when the alternating current is zero you get curves that show the natural distribution of the flux which would occur in a simple direct current machine, then as the alternating current rises, the reaction of the direct currents is neutralized, and finally you get a condition shown at the middle of the series, in which the alternating current actually overbalances the direct current in the armature. That occurs for the reason, that the alternating current rises to some value that is greater than the direct current, and therefore when the armature reaction due to the alternating current, overbalances the armature reaction which is due to the direct current, you get an effect which is shown where the maximum instantaneous value of the curve of magnetism is changed in its position and runs over the other way, causing a rise on the left hand side. Now I think we can trace the effect of the variation of the current still further in the efficiency curves of the machine. For instance, in Plate 10 you have the efficiency curve of the converter rising above the efficiency curve of the motor. In other words, the heating losses in the conductors are proportionally less when the machine is fully loaded and used as a rotary converter than when it is used as a direct current motor, for the reason that the current flowing in the armature is less, and that therefore the loss due to the current flowing in the armature is correspondingly smaller, and for this reason, largely, the efficiency of the converter rises for high loads. The losses due to the eddy currents and hysteresis would be practically the same, or even greater I think, in the case of the converter, owing to the fact that the armature reaction in this case, if anything, tends to increase rather than diminish the total field flux, and therefore any increase in efficiency is very largely due to the fact that the heating losses in the armature conductors are less, and also to the fact that there is no side pull on the shaft. There is less friction loss necessarily in the case of this rotary converter, than there is in the case of the motor.

MR. DUNN:—The curves presented by Professor Owens lead me to call attention to a physical fact which I think is not well known in electrical science, namely, the high resistance of certain forms of iron. The curves show a variation of the flux passing across the air gap, with each impulse of the current, and the variation is sufficiently great, as can be seen, to cause a good deal of loss from eddy currents.

The fact I wish to bring out is that, while the resistivity of iron is ordinarily seven times that of copper, the resistivity of cast-steel is about fifteen times that of copper or nearly double that of iron and the resistivity of cast-iron is about 65 times that of copper or 9 times that of iron. This fact shows, why we do not get enormous losses in the case of rotary transformers which have a variation in the field flux, as shown in this paper, the simple reason is that while there is change of magnetic induction in the pole pieces, it cannot produce eddy currents because of the abnormally high resistance of the cast-iron. This resistance of 65 times the resistance of copper makes the properties of the cast iron like those of a different metal, and I can only explain it as an extremely great increase in the resistance of copper is explained, when there are present impurities of phosphorus or sulphur. The reduction in the eddy currents is wonderful, and we have long been enjoying the advantages without knowing it. Professor Owen's machine is one in which a cast-iron field was used, and very likely the large variations shown do not cause excessive loss on that account.

MR. C. P. STEINMETZ:—In large rotary converters a very considerable loss of energy by local oscillation of the magnetic flux and consequent heating of the field pole pieces when solid is to be anticipated, and for this reason in such machines laminated field poles are ordinarily used.

Referring more particularly to Prof. Owens' paper, it is of great interest investigating what may be called the higher harmonics of armature reaction.

In the polyphase rotary converter the resultant armature reaction of the machine as direct current machine and as alternating current machine are equal but opposite, thus neutralizing each other and all that remains of armature reaction are effects of higher frequency which may be called higher harmonics of armature reaction. They are obviously present in alternating current generators and synchronous motors also, but they are overshadowed by the fundamental wave and thus less noticeable than in the rotary converter.

Besides these higher harmonics of armature reaction, further higher harmonics exist when the rotary converter is used to change from alternating to direct current, due to the difference in wave shape between the impressed alternating terminal voltage and the induced alternating counter E. M. F., which difference causes a current component to flow, consisting essentially of waves of higher frequency or higher harmonics.

The rotary converter has latterly become an eminently important piece of apparatus, by forming the connecting link between the alternating and the direct current. That is, giving a means to convert the alternating current received over long distance transmission lines into direct current for use.

In the rotary converter the induced direct current voltage and the induced alternating current voltage stand in a definite proportion.

In the single phase rotary converter their ratio is:

$$1 \div \frac{1}{\sqrt{2}}$$

Thus the ratio of the direct current and the energy component of alternating current corresponding thereto is:

$$1 \div \sqrt{2}$$

In a polyphase system we have to distinguish "star" voltage (in the three-phase system commonly called Y voltage), that is voltage between any terminal and the neutral point, or point of equal difference of potential from all phases, and "ring" voltage (in the three-phase system commonly called "delta" voltage), that is voltage between adjacent terminals of the system. In the same way we distinguish between star (or Y) current, that is current flowing from terminal to neutral point (this is the line current) and ring (or delta) current, that is current flowing from terminal to adjacent terminal.

The induced direct current E. M. F. and the induced star E. M. F. in the polyphase converter have the proportion:

$$1 \div \frac{1}{2\sqrt{2}}$$

The star E. M. F. and the ring E. M. F. of the n-phase system have the proportion:

$$1 \div 2 \sin \frac{\pi}{n}$$

Thus the induced direct current E. M. F. and the ring E. M. F. in the polyphase converter have the proportion:

$$1 \div \frac{\sin \frac{\pi}{n}}{\sqrt{2}}$$

Since the direct current power output and the alternating current power input, neglecting losses and phase displacement, are equal, we have :

The direct current and the alternating star current in the polyphase rotary converter have the ratio :

$$1 \div \frac{2\sqrt{2}}{n}$$

The direct current and the alternating ring current have the ratio :

$$1 \div \frac{\sqrt{2}}{n \sin \frac{\pi}{n}}$$

These current values refer to the energy component of alternating current corresponding to the direct current.

If a phase displacement exists between alternating E. M. F. and current, the wattless component of current has to be added by the parallelogram to above given values, and so has the current representing the losses in the converter, that is driving it as synchronous (or direct current) motor.

Derivation of these equations I have given in a lecture before Cornell University, published in the Sibley Journal, June, 1897, Vol. XI., No. 9.

The above given ratios of E. M. F'.s refer to the induced E. M. F's of the rotary converter. The ratio between the alternating terminal voltage and the direct current terminal voltage of the rotary converter differ more or less from the above given values, due to the drop of voltage in the resistance of the rotary converter and due to the difference of the shape of impressed alternating current wave and of counter E. M. F. wave; that is the maximum value of the alternating E. M. F. wave is equal to the direct current E. M. F. plus or minus resistance drop. Thus the effective value differs more or less from the above given values, sometimes 10 to 15°, according to the ratio between maximum and effective value of the alternating E. M. F. wave, that is according to the wave shape. In the above given values sine waves were assumed.

In general in every armature coil of the rotary converter the direct current and the energy component of alternating current flow more or less in opposition to each other.

The direct current in the armature coil is really a rectangular alternating current as shown in Figs. 8 and 9, as C reversing successively in adjacent coils by their passage under the brush.

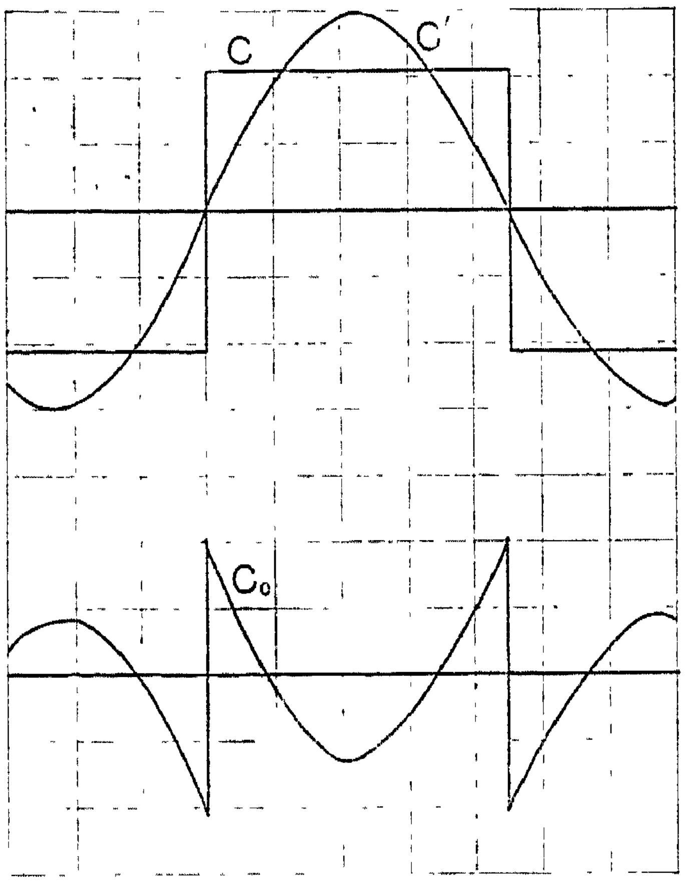

FIG. 8.

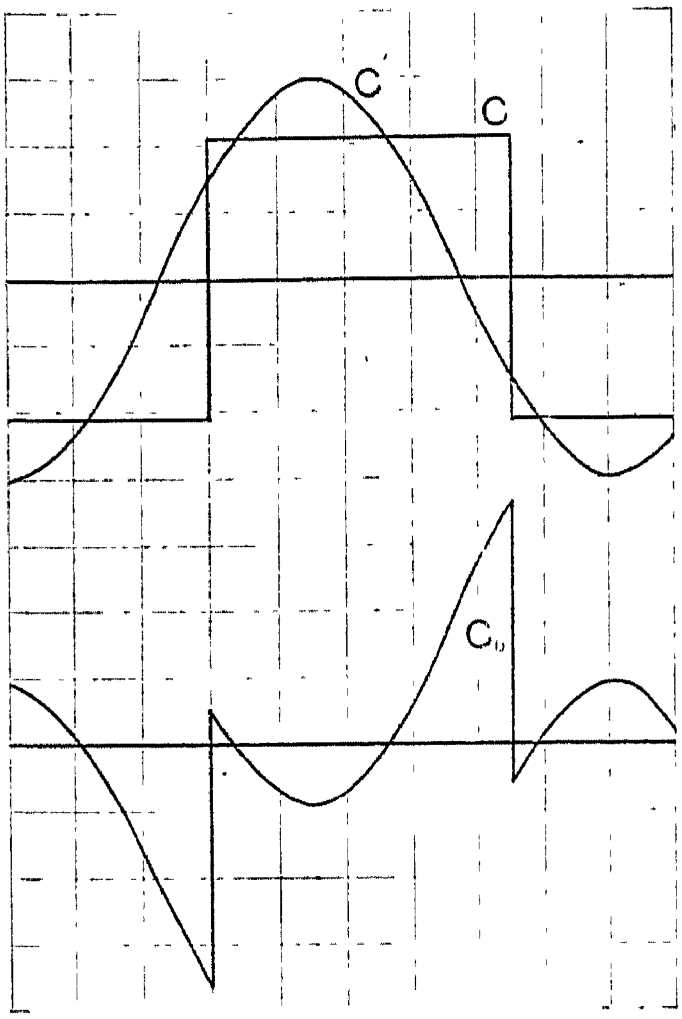

FIG. 9.

The alternating current C^1 is assumed as sine wave and is the same in all coils of the same phase, thus more or less displaced from the rectangular direct current wave.

The two currents are perfectly in opposition in a coil midways between two adjacent alternating leads, and in this coil the resultant current in the n-phase rotary converter is

$$C_0 = \frac{C}{2}\left(\frac{4 \sin \varphi}{n \sin \frac{\pi}{n}} - 1\right),$$

where

$$C = \text{direct current, and } \varphi = 2\,\pi\,N\,t,$$

it is shown in Fig. 1 as C_0.

In an armature coil displaced by phase angle ω from middle position between alternating leads, Fig. 9., the resultant current is

$$C_o = \frac{C}{2}\left(\frac{4 \sin (\varphi - \omega)}{n \sin \frac{\pi}{n}} - 1\right),$$

as shown in Fig. 9 as C_o.

Thus the effective value of current,

$$C_o = \frac{C}{2}\sqrt{\frac{8}{n^2 \sin^2 \frac{\pi}{n}} + 1 - \frac{16 \cos \omega}{n\, \pi \sin \frac{\pi}{n}}}.$$

Hence, since $\frac{C}{2}$ is the direct current in the armature coil, the relative heating effect of the resultant current in the rotary converter, and the direct current is:

$$\gamma\, \omega = \left(\frac{C_o}{\frac{C}{2}}\right)^2 = \frac{8}{n^2 \sin^2 \frac{\pi}{n}} + 1 - \frac{16 \cos \omega}{n\, \pi \sin \frac{\pi}{n}},$$

and integrating over the whole armature, it is:

$$\Gamma = \frac{8}{n^2 \sin^2 \frac{\pi}{n}} + 1 - \frac{16}{\pi^2},$$

the ratio of the $C^2 R$ in the rotary converter and the direct current machine of the same output.

In consequence hereof, regarding heating of the armature, the rotary converter can be rated at $\frac{1}{\sqrt{\Gamma}}$ of the output of the same machine as direct current machine. This is

.85 of the output of the machine as direct current machine in a single phase rotary converter,

1.34 in the three-phase rotary converter
1.64 " quarter-phase " "
1.96 " six-phase " "
2.31 " infinite phase " "

Coming now to the armature reaction of the rotary converter.

The armature reaction of the direct current C with m turns on the armature of a bipolar machine (in a multipolar machine C and m refer to one pair of poles) is,

$$F = \frac{m\, C}{2}\, avg \cos \Big|_{-\frac{\pi}{2}}^{+\frac{\pi}{2}}$$

$$= \frac{m\, C}{\pi}$$

In the n-phase rotary converter the ampere turns per phase on the armature (per pair of poles) are:

$$\frac{m\,C_1}{n} = \frac{\sqrt{2}\,m\,C}{n^2 \sin \frac{\pi}{n}}$$

Where C_1 = alternating ring current and C the corresponding direct current.

Thus their resultant, since these ampere-turns are distributed over $1 / n$ of the circumference:

$$f_1 = \frac{m\,C}{n}\, avg \cos \Big|_{-\frac{\pi}{n}}^{+\frac{\pi}{n}}$$

$$= \frac{\sqrt{2}\,m\,C}{\pi\,n}$$

and consequently the resultant armature reaction of all n phases:

$$F_1 = \frac{n\sqrt{2}}{2} f_1 \quad *)$$

$$= \frac{m\,C}{\pi}$$

that is equal (but opposite) to that of the direct current. Therefore, while in a direct current or alternating current machine a considerable increase of field strength is required with increasing load to take care of the armature reaction, in a rotary converter practically no change of field strength with change of load is required, except where phase displacements are intentionally produced thereby.

The polarization of the armature due to the energy component of alternating current is in quadrature with the field M. M. F. Thus the armature reaction of the wattless component of alternating current is in phase with the field M. M. F. with a lagging, in opposition with a leading current in a machine converting from direct to alternating current. Hence, it is always magnetizing or demagnetizing, but never distorting.

In the polyphase rotary converter no distortion of the magnetic field exists, except that due to the small energy component of alternating (or direct) current driving the machine as motor, that is supplying the internal losses.

The resultant armature reaction due to the energy component of alternating current corresponding to the direct current is zero. Thus all that exists of armature reaction, is:

The small armature reaction due to the current driving the machine as motor, which is in quadrature or distorting, and of fundamental frequency.

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* "Theory and Calculation of Alternating Current Phenomena," Steinmetz, page 354.

The armature reaction of the wattless component of alternating current, if such exists, which is magnetizing or demagnetizing and of fundamental frequency.

The higher harmonics of armature reaction investigated by Prof. Owens.

The higher harmonics of armature reaction produced by a difference of wave shape between impressed and counter E. M. F. when converting from alternating to direct current.

Either of the latter two reactions is oscillating.

In a single phase rotary converter the armature reaction of the alternating current is pulsating, thus the resultant armature reaction oscillating, thereby causing a sweeping flux, which is very objectionable for sparkless commutation.

The polyphase rotary converter is self-starting from rest, but in this case requires a very large current and gives a small torque, that is, is similar to the induction motor without resistance in the secondary circuit.

The polyphase rotary converter offers the most convenient means of controlling the voltage of an alternating current system by phase relation. By varying the relative proportion of impressed and counter E. M. F. by a change of the field excitation of the rotary converter, either by hand, or automatically by the combination of shunt and series field, leading or lagging currents can be produced at will, and thereby the self-induction of the circuit between generator and rotary converter made to raise or lower the voltage at the latter's terminals. Besides the rotary converter can be used to compensate for lagging currents of induction motors, etc.

The use of the rotary converter to change from direct to alternating current is somewhat dangerous, since any change in the alternating current system supplied by the rotary converter, which causes lagging currents to flow, will react demagnetizing upon the rotary converter field, and thereby cause the rotary converter to speed up in the same way as any direct current motor with reduced field strength speeds up. Therefore when used in this manner, means have to be provided to check automatically any undue acceleration caused by lagging alternating currents.

PROF. THOMSON:—There is just one consideration I would like to call attention to in the discussion of this subject, and that is that the machine which is excited as a constant potential machine has virtually on its field a copper band which is of course in inductive relation to the mass of the field such as would tend to prevent variation in the total flux through the whole section, but of course would not prevent variation in flux relatively, the one portion of the pole piece to the other, and it would be of course an interesting matter to determine just how far this difference prevents the discovery of other variations or greater variations than those found.

THE PRESIDENT:—Are there any further remarks on this subject? If not I will ask Vice President Steinmetz to kindly take the Chair.

Mr. Steinmetz took the Chair.

THE CHAIRMAN:—The next paper in order is Professor Jackson's paper on "Electrical Cooking Apparatus." In Mr. Jackson's absence I will ask the Secretary to read the paper.

A paper presented at the 14th General Meeting of the American Institute of Electrical Engineers, Eliot, Me., July 28th, 1897. Vice-President Steinmetz in the Chair.

THE ECONOMY AND UTILITY OF ELECTRICAL COOKING APPARATUS.

BY JOHN PRICE JACKSON.

The tests of electrical cooking apparatus detailed in this paper were made with the hope of obtaining a method of cooking that would be satisfactory with a minimum risk of fire. During the past winter a serious fire, which might readily have become disastrous, occurred in one of the buildings of the college with which the writer is connected, caused by the use of an alcohol stove. As this institution is lighted and furnished with power by electricity, it naturally was felt that such a danger should be avoided, if possible, by the use of electrical appliances. It was also desired to ascertain whether at least a portion of the cooking in the Woman's Department of the college could not be done satisfactorily by electricity.

To determine these points, I procured from the American Electrical Heating Corporation, of Boston, through the courtesy of Mr. J. E. Sayles, the following pieces of apparatus:

1 oven, 13″ × 9″ × 18″, having three heats, 3, 10 and 17 amperes respectively.

3 stoves of 2, 4 and 5 amperes respectively.

2 flatirons of 1.5 and 6 amperes capacity.

1 broiler of 12 amperes capacity.

1 curling iron of ½ ampere capacity.

The pressure used by these is 110 volts.

The stoves are round disks of iron, on the under side of which the heating wires are imbedded in a non-conducting, incombustible compound. The oven is a box, so thoroughly heat-insulated that the outside metal covering never reaches a temperature uncomfortable to the hand. The broiler is made of a corrugated metal surface, slightly tipped from the horizontal, with a drip groove at the lower edge for catching the meat juices. The flatirons are similar in construction to the stoves, the larger one having a low current switch, which enables the operator to control the heat.

In all these appliances the heating coils are so arranged that the energy is largely concentrated at useful points. They are also supplied with supports and bases which will not conduct heat.

The efficiencies of the two larger stoves were obtained by heating two pounds of water to the boiling point and measuring the power supplied by a calibrated wattmeter. The cooking vessels used were ordinary stewing pans, with the bases nearly of the same size as the tops of the stoves. The efficiencies, considering the ratio between the amount of heat absorbed by the water and the amount received by the stoves were:

For the larger or No. 1, 48.9 per cent.
For the next size, " 2, 43.1 "

These efficiencies could be increased by having the pans made to fit the stoves exactly, and still further by carefully covering the pans, lids and exposed portions of the stoves with a non-conductor of heat.

When it is desired to boil water, the best plan is to place an immersion coil in a properly heat-insulated pot; such an arrangement should give an efficiency of from 90 to 100 per cent. We unluckily did not have such a coil at our disposal.

It was impossible to measure the cooking efficiency of the oven, but as it was merely warm on the outside after potatoes or bread had been baked and "done to a turn," the efficiency is high. In baking, the current was turned on and the oven allowed to heat for five minutes before the articles to be cooked were placed within, and the current was turned off from ten to twenty minutes before the baking was done, when the heat of the oven was sufficient to complete the operation. The broiler was manipulated in much the same manner, thus utilizing the greatest possible amount of heat. This electrical apparatus was used for several weeks in cooking most of the meals for a family of six.

The following table indicates the amount of cooking done for the first breakfast, dinner and supper, respectively, and may be taken as a fair average of the whole period.

All costs have been estimated on the basis of 10 cents per kilowatt hour, the average rate charged for residence electrical supply in a near-by town. The foods were not measured, as it was believed more desirable to determine whether in a long period of cooking the apparatus would prove satisfactory for a family of given size.

The largest stove is designated No. 1; the next size, No. 2; the third size, No. 3; the broiler, B and the oven, o.

BREAKFAST.

TIME.	UTENSILS.	FOOD.	WATTS.
6.55	No. 1, on	Rolled Oats	
6.55	2, on	Coffee	844
7.45	1, off		
7.45	B, on	Beefsteak	1500
7.55	2, off		1155
8.05	B, off		

Kilowatt Hours, 1.355 Cost, 11.46 cents.

DINNER.

TIME.	UTENSILS.	FOOD.	WATTS.
10.51	No. O, on	Beef Roast Potatoes Pie	1610
10.55			
11.35			
11.46	1, on	Asparagus	1990
12.05	O. off		
12.05	2, on	Coffee	1180
12.11	B, on	Toast for Asparagus	2200
12.29	1, off		1835
12.32	B, off		
12.32	2, off		

Kilowatt Hours, 2.98 Cost, 29.8 cents.

SUPPER.

TIME.	UTENSILS.	FOOD.	WATTS.
4.59	No. 1, on	Cocoa	630
5.15	2, on	Potato Cakes	1010
5.16	B, on	Omelet	2100
5.22	2, off		1700
5.26	B, off		
5.26	2, on		1130
5.43	2, off		640
5.44	1. off		

Kilowatt Hours, 8.39 Cost, 8.39 cents.

Four pies can be baked in the oven at an expenditure of .62 kilowatt hours and a cost of 6.2 cents or 2.05 cents per pie. Two large loaves of bread were baked with the current on the oven 50 minutes, at an expenditure of 1.22 kilowatt hours, a cost of 12.2 cents or 6.1 cents per loaf. Four rather small-sized loaves could have been baked as readily. Biscuits with about the same expenditure of energy as in the case of pies. The broiler utilized about the same amount of energy for all kinds of meat as indicated in the table. The cost of soup sufficient for the family was about 4.5 cents.

The result of the whole series of meals was a cost for electricity of 13.1 cents per meal. The heating of water for washing the dishes took an additional .35 of a kilowatt hour per meal, which raises the cost to 16.6 cents per meal.

To determine the relative cost of cooking with electricity and coal, the same foods were cooked on the No. 8 Othello coal stove ordinarily used by the family. The coal was carefully weighed. The results gave an average of 12.6 pounds per meal, which at $5.00 per ton gives a cost of 3.15 cents per meal.

The results show the cost of cooking by coal to be about 19 per cent of the cost of cooking by electricity.

Ironing was done for the same household a number of times. The heavy articles were done with the large iron; while for fancy dresses and light articles, the small iron was used. The average time taken was four hours, and the expenditure of energy in kilowatt hours was 2.27. This made the cost of the ironing 22.7 cents.

An equal number of tests was made using the coal range, the fuel being carefully weighed. For the same sized wash, the ironing took five hours, at a cost of 12.25 cents. This shows the cost of energy by the use of coal to be 54 per cent. of that by electricity.

The results of the cooking tests seem to indicate that for the usual cooking of a family for the whole year, the expense would be larger than would be ordinarily acceptable, notwithstanding the great advantages in other respects. However, in the following classes the utility of electrical cooking utensils should be great:

1. For light housekeeping, such as is practiced in small city apartments, and in many larger houses during the summer months, no other method presents so many desirable features. The dirt of coal and ashes, disagreeable gases and abnormal temperature due to a coal stove are entirely avoided. For such housekeeping a disk stove using 500 or 600 watts and a broiler using about 1200 watts would be sufficient for a small family and would cost from $20.00 to $30.00. A teakettle or immersion coil might be added at a cost of from $6.00 to $10.00. A special pair of wires would of necessity have to be run into the cooking room from

the house or apartment supply mains. The latter would ordinarily warrant the extra call that would be made upon them in this way. For similar purposes coal oil, gas or gasoline are frequently used, but with the inherent disadvantages of greater heat in the room, offensive odors, comparative uncleanliness and danger.

2. This form of cooking apparatus could be used with facility in boarding houses and restaurants for purposes which require an even temperature such as is needed in baking griddle cakes, boiling eggs, etc.

3. Where electricity is available, nothing could be more convenient than a small electrical stove, requiring 300 or 400 watts, for the many uses to which at present the alcohol flame is put, such as the afternoon tea-kettle, chafing-dish, toaster, etc. This use of alcohol is most unsafe as regards danger from fire, and could well be discarded for electricity, which is absolutely safe when properly installed, as well as being more convenient and better in other respects.

4. In the shop, the glue pot, solder pot, brazing iron, etc., can be heated advantageously by electricity and one of the most gratifying consequences of our experiments has been the decision to put such an equipment in our college shops.

5. The test of the electrical flatirons showed them more economical than the old form, when the saving of labor is taken into account. Not only is there a saving in time, but the severity of labor is much lessened. Our experience is that a laundress who has used an electrical iron would be exceedingly unwilling to go back to the old form.

A small flatiron of two or three amperes attached to the ordinary lighting fixture in a dressing room is a great convenience; and with the electric tea-kettle and curling-iron is destined to become essential in the modern home.

Concerning the question whether the use of electricity had proved satisfactory in its operations in the cooking tests described, the housekeeper in charge said: "The instruments were excellent in every respect. We were able to cook more rapidly, to keep the heat at just the right point, and could readily prevent over-cooking or under-cooking. While we were using electricity every dish was perfect. When I think of these advantages and of the cleanliness and convenience of the utensils, I sincerely hope that some of them at least may be retained in the house permanently."

The general results of the tests were of such a nature that the writer is warranted in the belief that if central station managers would more generally introduce exhibition equipments of these domestic utensils, a new call on their station capacity would develop, of which the larger proportion would be during the light load periods.

I wish to acknowledge my indebtedness to Mr. Rudolph F. Kelker, of Harrisburgh, Pa., for his valuable aid in carrying out the work briefly described above.

DISCUSSION.

PROF. THOMSON:—I am sorry that the author of the paper is not here to give us a little information that it seems to me ought to be had, especially in this country of pie. The cost of baking a pie is given, but the size of the pie is not mentioned. In the same way the cost of biscuits is said to be the same as that of pie. This looks a little suspicious, as biscuits are usually small. Whether for the purpose of comparison the size of the biscuits ought to be increased to that of the pie, or the size of the pie to be reduced to that of the biscuits, I do not know. As an interesting fact in this matter of cooking, I may mention that many years ago, I think about 1877, in a lecture, I showed as a novelty at that time,—dynamos were then a novelty—I showed the experiment of boiling an egg, and it was at that time quite a novelty. The experiment was performed by simply immersing a little coil of german silver wire. There was very little water, and in that operation you could bring it to a boiling point in a short space of time. I cooked the egg beautifully and ate it after the lecture.

PROF. OWENS:—The statement that electrical cooking apparatus is likely to help out the station load diagram, I think is an error. The breakfast cooking, and dinner cooking will certainly come about the time when the heavy morning and evening loads are on. I note that he has made no comparison with the gas stove which seems to be the favorite utensil for cooking in a small way. Not having had the experience with domestic cooking apparatus etc., that Prof. Jackson has, I am unable to criticise the figures he gives for the cooking of actual food material; but I conducted a long series of experiments a year ago to determine the efficiency of various pieces of electric cooking apparatus, using water in every case as a means of absorbing the power, and I am sorry I have not the results with me, or the curves, but I will be glad to send a few of them in as a written communication.

THE SECRETARY:—I regret, Mr. Chairman, that this paper came to hand at such a late hour that I could not make any inquiries in regard to these matters. I am not very well posted on the subject of cooking by electricity, but my thoughts turned in the same direction as Prof. Thomson's, because, being a native of New England, and a long time sojourner in New York, I have had experience with different forms of pie and different sizes of loaves of bread, and I have seen loaves of bread baked in a dish-pan in camp. If you could bake one of those for six cents, it would perhaps be a reasonable cost. I was unable to get any further information, and this paper was printed after I left. I received it since I arrived here.

THE CHAIRMAN:—Is there any further discussion? If there is no further discussion, the programme of the June meeting, 1897, is closed. But before the meeting adjourns, I think I express the sentiment of the INSTITUTE by expressing the heartfelt thanks of the INSTITUTE to the residents of Greenacre, and especially the ladies for their hospitality, and the very pleasant reception they have accorded to us. In the name of the INSTITUTE I thank them. (Applause).

The General Meeting then adjourned, *sine die.*

Associate Members elected by the Executive Committee, August 13th, 1897.

Name	Address	Endorsed by
BARNES, CHAS. R.	City Electrician and Electrical Expert to State R. R. Commission, Rochester, N. Y.	Vincent C King,Jr. Joseph Broich. Geo. A. Redman.
BALDWIN, ALFRED DE V.	Selling Agent, Crocker-Wheeler Electric Co., P. O. Box 267: residence, 708 W. 85 St., New York.	S. S. Wheeler. F. B. Crocker. Gano S. Dunn.
EMERICK, LOUIS W.	Electrical Engineer, The Solvay Process Co., Syracuse, N. Y.; residence, 208 East Jefferson St., Syracuse, N. Y.	Paul T. Brady. Frank Land. John A. Seely.
FAY, ROBERT H.	Supt. of Fire Alarm and Inspector of Wires, Chicopee Falls, Mass.	Giles Taintor. J. W. Hyde. R. W. Pope.
GRIFFEN, JOHN D.	Inventor, Electric Conduit and Electric Signaling Apparatus, 60 Broadway, residence, 304 West 90th St., New York.	Wm. J. Hammer. T. C. Martin. J. P. Wintringham
HOPEWELL, Chas. F.	Inspector of Wires, Supt. of Lamps, Fire Alarm and Police Telegraph City of Cambridge, City Hall; residence, 82 Magazine Street, Cambridgeport, Mass.	C. C. Chesney. Chas. R. Cross. Wm. L. Puffer.
JACKSON, WM. B.	Manager, Peninsular Light, Power and Heat Co., Grand Rapids, Mich.; residence, 24 Fountain St., Grand Rapids, Mich.	D. C. Jackson. Henry A. Lardner. J. P. Jackson.
KLAUDER, RUDOLPH H.	Electrical Engineer, The Electric Storage Battery Co, Philadelphia, Pa.	Chas. Blizard. Robt. Mc A Lloyd. Joseph Wetzler.
NIMIS, ALBERT A.	Assistant Electrician, B. Altman & Co.; residence, 175 3rd Ave., New York.	E. P. Clark. R. W. Pope. Joseph Wetzler.
PILLSBURY, CHAS. L.	City Electrical Inspector, City Hall; residence, 1109 Hawthorne Ave., Minneapolis, Minn.	W. M. Stine. Geo. D. Shepardson B. J. Arnold.
SHAFFNER, S. C.	Supt. and Electrician. Electric Lighting Co. of Mobile, Box 234 Mobile, Ala.	A. M. Schoen. E. W. Trafford. W. E. Moore.
WEISE, WILL M. T.	Manager, Weise Bros., Library Building, Davenport, Iowa.	Leo Daft. Maurice Coster. L. K. Comstock
WIEDERHOLD, OSCAR, Total, 13.	Electrical Engineer, Wiederhold & Stoeckel, 257 Front St., New York; residence, Summit, N. J.	Chas. D. Shain. Wm. J. Hammer. H. B. Coho.

THE

NATIONAL ELECTRICAL CODE,

AS ADOPTED BY THE

NATIONAL CONFERENCE ON STANDARD ELECTRICAL RULES.

New York, March 18th and 19th, 1896.

GENERAL PLAN

GOVERNING THE ARRANGEMENT OF RULES.

CLASS A.—**Central Stations, Dynamo, Motor and Storage-Battery Rooms, Transformer Sub-stations, etc.** Rules 1 to 11.

CLASS B.—**Outside Work**, all systems and voltages. Rules 12 and 13.

CLASS C.—**Inside Work.** Rules 14 to 39. Subdivided as follows:

- **General Rules,** applying to all systems and voltages. Rules 14 to 17.
- **Constant-Current** systems. Rules 18 to 20.
- **Constant-Potential** systems.
  - All voltages. Rules 21 to 23.
  - Voltage not over 300. Rules 24 to 31.
  - Voltage between 300 and 3,000. Rules 32 to 37.
  - Voltage over 3,000. Rules 38 to 39.

CLASS D.—**Specifications for Wires and Fittings.** Rules 40 to 55.

CLASS E.—**Miscellaneous.** Rules 56 to 59.

CLASS F.—**Marine Wiring.** Rules 60 to 72.

GENERAL SUGGESTIONS.

In all electric work conductors, however well insulated, should always be treated as bare, to the end that under no conditions, existing or likely to exist, can a grounding or short circuit occur, and so that all leakage from conductor to conductor, or between conductor and ground, may be reduced to the minimum.

In all wiring special attention must be paid to the mechanical execution of the work. Careful and neat running, connecting, soldering, tapping of conductors and securing and attaching of fittings, are specially conducive to security and efficiency, and will be strongly insisted on.

In laying out an installation, except for constant-current systems, the work should, if possible, be started from a centre of distribution, and the switches and cut outs, controlling and connected with the several branches, be grouped together in a safe and easily accessible place, where they can be readily got at for attention or repairs. The load should be divided as evenly as possible among the branches, and all complicated and unnecessary wiring avoided.

The use of wire-ways for rendering concealed wiring permanently accessible is most heartily indorsed and recommended; and this method of accessible concealed construction is advised for general use.

Architects are urged, when drawing plans and specifications, to make provision for the channeling and pocketing of buildings for electric light or power wires, and in specifications for electric gas lighting to require a two-wire circuit, whether the building is to be wired for electric lighting or not, so that no part of the gas fixtures or gas piping be allowed to be used for the gas-lighting circuit.

CLASS A.

STATIONS AND DYNAMO ROOMS

Includes Central Stations, Dynamo, Motor and Storage Battery Rooms, Transformer Sub-Stations, Etc.

1. Generators.—

a. Must be located in a dry place.

b. Must never be placed in a room where any hazardous process is carried on, nor in places where they would be exposed to inflammable gases or flyings of combustible materials.

c. Must be insulated on floors or base frames, which must be kept filled to prevent absorption of moisture, and also kept clean and dry. Where frame insulation is impracticable, the inspection department having jurisdiction may, in writing, permit its omission, in which case the frame must be permanently and effectively grounded.

A high-potential machine which, on account of great weight or for other reasons, can not have its frame insulated from the ground, should be surrounded with an insulated platform. This may be made of wood, mounted on insulating supports, and so arranged that a man must always stand upon it in order to touch any part of the machine.

In case of a machine having an insulated frame, if there is trouble from static electricity due to belt friction, it should be overcome by placing near the belt a metallic comb connected with the earth, or by grounding the frame through a very high resistance of not less than 200 ohms per volt generated by the machine.

d. Every constant-potential generator must be protected from excessive current by a safety fuse, or equivalent device of approved design in each lead wire.

These devices should be placed on the machine or as near it as possible.

Where the needs of the service make these devices impracticable, the Inspection Department having jurisdiction may, in writing, modify the requirements.

e. Must each be provided with a waterproof cover.

f. Must each be provided with a name-plate, giving the maker's name, the capacity in volts and amperes, and normal speed in revolutions per minute.

2. Conductors.—

From generators to switchboards, rheostats or other instruments, and thence to outside lines.

a. Must be in plain sight or readily accessible.

b. Must have an *approved* insulating covering as called for by rules in Class "C" for similar work, except that in central stations, on exposed circuits, the wire which is used must have a heavy braided non-combustible outer covering.

Bus bars may be made of bare metal.

c. Must be kept so rigidly in place that they can not come in contact.

d. Must in all other respects be installed under the same precautions as required by rules in Class "C" for wires carrying a current of the same volume and potential.

3. Switchboards.—

a. Must be so placed as to reduce to a minimum the danger of communicating fire to adjacent combustible material.

Special attention is called to the fact that switchboards should not be built down to the floor, nor up to the ceiling, but a space of at least ten to twelve inches should be left between the floor and the board, and from eighteen to twenty-four inches between the ceiling and the board in order to prevent fire from communicating from the switchboard to the floor or ceiling, and also to prevent the forming of a partially concealed space very liable to be used for storage of rubbish and oily waste.

b. Must be made of non-combustible material or hardwood in skeleton form, filled to prevent absorption or moisture.

c. Must be accessible from all sides when the connections are on the back, but may be placed against a brick or stone wall when the wiring is entirely on the face.

d. Must be kept free from moisture.

e. Bus bars must be equipped in accordance with the rules for placing conductors.

4. Resistance Boxes and Equalizers.—

(*For construction rules, see No. 52.*)

a. Must be placed on a switchboard or, if not thereon, at a distance of a foot from combustible material, or separated therefrom by a non-inflammable, non-absorptive, insulating material.

5. Lightning Arresters.—

(*For construction rules, see No. 55.*)

a. Must be attached to each side of every overhead circuit connected with the station.

It is recommended to all electric light and power companies, that arresters be connected at intervals over systems in such numbers and so located as to prevent ordinary discharges entering (over the wires) buildings connected to the lines.

b. Must be located in readily accessible places away from combustible materials, and as near as practicable to the point where the wires enter the building.

Station arresters should generally be placed in plain sight on the switchboard.

In all cases, kinks, coils and sharp bends in the wires between the arresters and the out door lines must be avoided as far as possible.

c. Must be connected with a thoroughly good and permanent ground connected by metallic strips or wires having a conductivity not less than that of a No. 6 B. & S. copper wire, which must be run as nearly in a straight line as possible from the arresters to the earth connection.

Ground wires for lighting arresters must not be attached to gas pipes within the buildings.

It is often desirable to introduce a choke coil in the circuit between the arresters and the dynamo. In no case should the ground wire from a lightning arrester be put into iron pipes, as these would tend to impede the discharge.

6. Care and Attendance.—

a. A competent man must be kept on duty where generators are operating.

b. Oily waste must be kept in *approved* metal cans and removed daily.

Approved waste cans shall be made of metal, with legs raising can three inches from the floor, with self-closing covers.

7. Testing of Insulation Resistance.—

a. All circuits must be provided with reliable ground detectors. Detectors which indicate continously, and give an instant and permanent indication of a ground are preferable. Ground wires from detectors must not be attached to gas pipes within the building.

b. Where continuously indicating detectors are not feasible, the circuits should be tested at least once per day, and preferably oftener.

c. Data obtained from all tests must be preserved for examination by the Inspection Department having jurisdiction.

These rules on testing to be applied at such places as may be designated by the Inspection Department having jurisdiction.

8. Motors.—

a. Must be insulated on floors or base frames, which must be kept filled to prevent absorption of moisture ; and must be kept clean and dry. Where frame insulation is impracticable, the Inspection Department having jurisdiction may, in writing, permit its omission, in which case the frame must be permanently and effectively grounded.

A high-potential machine which, on account of great weight or for other reasons, can not have its frame insulated, should be surrounded with an insulated platform. This may be made of wood, mounted on insulating supports, and so arranged that a man must stand upon it in order to touch any part of the machine.

In case of a machine having an insulated frame, if there is trouble from static electricity due to belt friction, it should be overcome by placing near the belt a metallic comb connected to the earth, or by grounding the frame through a very high resistance of not less than 200 ohms per volt generated by the machine.

b. Must be wired under the same precautions as required by rules in Class "C," for wires carrying a current of the same volume and potential.

The leads or branch circuits should be designed to carry a current at least fifty per cent. greater than that required by the rated capacity of the motor to provide for the inevitable overloading of the motor at times without over-fusing the wires.

c. The motor and resistance box must be protected by a cut out and controlled by a switch (see No. 17 *a*), said switch plainly indicating whether "on" or "off." Where one-quarter horse-power or less is used on low-tension circuits a single-pole switch will be accepted. The switch and rheostat must be located within sight of the motor, except in such cases where special permission to locate them elsewhere is given, in writing, by the Inspection Department having jurisdiction.

d. Must have their rheostats or starting boxes located so as to conform to the requirements of Rule 4.

In connection with motors the use of circuit breakers, automatic starting boxes and automatic under-load switches is recommeded, and they *must* be used when required.

e. Must not be run in series-multiple or multiple-series.

f. Must be covered with a water-proof cover when not in use, and, if deemed necessary by the Inspection Department having jurisdiction, must be inclosed in an approved case.

From the nature of the question the decision as to what is an approved case must be left to the Inspection Department having jurisdiction to determine in each instance.

g. Must, when combined with ceiling fans, be hung from insulated hooks, or else there must be an insulator interposed between the motor and its support.

h. Must each be provided with a name-plate, giving the maker's name, the capacity in volts and amperes and the normal speed in revolutions per minute.

9. Railway Power Plants.—

a. Must be equipped in each feed wire before they leave the station with an *approved* automatic circuit breaker (see No. 44) or other device, which will immediately cut off the current in case of a ground. This device must be mounted on a fireproof base, and in full view and reach of the attendant.

10. Storage or Primary Batteries.—

a. When current for light and power is taken from primary or secondary batteries, the same general regulations must be observed as applied to similar apparatus fed from dynamo generators developing the same difference of potential.

b. Storage battery rooms must be thoroughly ventilated.

c. Special attention is directed to the rules for rooms where acid fumes exist. (See No. 24, *j* and *k*.)

d. All secondary batteries must be mounted on non-absorptive, non-combustible insulators, such as glass, or thoroughly vitrified and glazed porcelain.

e. The use of any metal liable to corrosion, must be avoided in connections of secondary batteries.

11. Transformers.—

(*For construction rules see No. 54.*)

a. In central or sub-stations the transformers must be so placed that smoke from the burning out of the coils or the boiling over of the oil (where oil filled cases are used) could do no harm.

CLASS B.

OUTSIDE WORK.

All Systems and Voltages.

12. Wires.—

a. Service wires must have an *approved* rubber insulating covering. (See No. 40 *a.*) Line wires, other than services, must have an *approved* weather-proof, or rubber insulating covering. (See No. 40 *a* and *b.*) All the wires must have an insulation equal to that of the conductors they confine.

b. Must be so placed that moisture can not form a cross connection between them, not less than a foot apart, and not in contact with any substance other than their insulating supports. Service blocks must be covered over their entire surface with at least two coats of waterproof paint.

c. Must be at least seven feet above the highest point of flat roofs, and at least one foot above the ridge of pitched roofs over which they pass or to which they are attached.

d. Must be protected by dead insulated guard iron or wires from possibility of contact with other conducting wires or substances to which current may leak. Special precautions of this kind must be taken where sharp angles occur, or where any wires might possibly come in contact with electric light or power wires.

e. Must be provided with petticoat insulators of glass or porcelain. Porcelain knobs or cleats and rubber hooks will not be approved.

f. Must be so spliced or joined as to be both mechanically and electrically secure without solder. The joints must then be soldered, to insure preservation, and covered with an insulation equal to that on the conductors.

All joints must be soldered, even if made with some form of patent splicing device. This ruling applies to joints and splices in all classes of wiring covered by these rules.

g. Must, where they enter buildings, have drip loops outside, and the holes through which the conductors pass must be bushed with non-combustible, non-absorptive insulating tubes slanting upward toward the inside.

h. Telegraph, telephone and similar wires must not be placed on the same cross-arm with electric light or power wires.

i. The metallic sheathes to cables must be permanently and effectively connected to "earth."

TROLLEY WIRES.

j. Must not be smaller than No. 0 B. & S. copper or No. 4 B. & S. silicon bronze, and must readily stand the strain put upon them when in use.

k. Must have a double insulation from the ground. In wooden pole construction, the pole will be considered as one insulation.

l. Must be capable of being disconnected at the power plant, or of being divided into sections, so that, in case of fire on the railway route, the current may be shut off from the particular section and not interfere with the work of the firemen. This rule also applies to feeders.

m. Must be safely protected against accidental contact where crossed by other conductors.

Guard wires should be insulated from the ground and should be electrically disconnected in sections of not more than 300 feet in length.

GROUND RETURN WIRES.

n. For the diminution of electrolytic corrosion of underground metal work, ground return wires must be so arranged that the difference of potential between the grounded dynamo terminal and any point on the return circuit will not exceed twenty five volts.

It is suggested that the positive pole of the dynamo be connected to the trolley line, and that whenever pipes or other underground metal work are found to be electrically positive to the rails or surrounding earth, that they be connected by conductors arranged so as to prevent as far as possible current flow from the pipes unto the ground.

13. Transformers.—

(*For construction rules, see No. 54.*)

a. Must not be placed inside of any building, excepting central stations, unless by special permission of the Inspection Department having jurisdiction.

b. Must not be attached to the outside walls of buildings unless separated therefrom by substantial supports.

CLASS C.

INSIDE WORK.

All Systems and Voltages.

GENERAL RULES—ALL SYSTEMS AND VOLTAGES.

14 Wires.—

(*For special rules, see Nos. 18, 24, 32, 38 and 39.*)

a. Must not be of smaller size than No. 14 B. & S., except as allowed under Rules 24*u* and 40*c*.

b. Tie wires must have an insulation equal to that of the conductors they confine.

c. Must be so spliced or joined as to be both mechanically and electrically secure without solder; they must then be soldered to insure preservation, and the joint covered with an insulation equal to that on the conductors.

Stranded wires must be soldered before being fastened under clamps or binding screws, and when they have a conductivity greater than No. 10 B. & S. copper wire, they must be soldered into lugs.

All joints must be soldered, even if made with some form of patent splicing device. This ruling applies to joints and splices in all classes of wiring covered by these rules.

d. Must be separated from contact with walls, floors timbers or partitions through which they may pass by non-combustible, non-absorptive insulating tubes, such as glass or porcelain.

Bushings must be long enough to bush the entire length of the hole in one continuous piece, or else the hole must first be bushed by a continuous waterproof tube, which may be a conductor, such as iron pipe; the tube then is to have a non-conducting bushing pushed in at each end so as to keep the wire absolutely out of contact with the conducting pipe.

e. Must be kept free from contact with gas, water or other metallic pipings, or any other conductors or conducting material which they may cross, by some continuous and firmly fixed non-conductor, creating a separation of at least one inch. Deviations from this rule may sometimes be allowed by special permission.

f. Must be so placed in wet places that an air space will be left between conductors and pipes in crossing, and the former must be run in such a way that they cannot come in contact with the pipe accidentally. Wires should be run over, rather than under, pipes upon which moisture is likely to gather or which, by leaking, might cause trouble on a circuit.

15. Underground Conductors.—

a. Must be protected, when brought into a building, against moisture and mechanical injury, and all combustible material must be kept removed from the immediate vicinity.

b. Must not be so arranged as to shunt the current through a building around any catch-box.

16. Table of Carrying Capacity of Wires.—

Below is a table showing the allowable carrying capacity of wires containing ninety-eight per cent. pure copper, which must be followed in placing interior conductors:

	TABLE A. Rubber Covered Wires. See No. 40 *a*.	TABLE B. Weatherproof Wires. See No. 40 *b*.
B. & S. G.	Amperes.	Amperes.
18	3	5
16	6	8
14	12	16
12	17	23
10	24	32
8	33	46
6	46	65
5	54	77
4	65	92
3	76	110
2	90	131
1	107	156
0	127	185
00	150	220
000	177	262
0000	210	312
Circular Mills.		
200,000	200	300
300,000	270	400
400,000	330	500
500,000	390	590
600,000	450	680
700,000	500	760
800,000	550	840
900 000	600	920
1,000,000	650	1,000
1,100.000	690	1,080
1,200,000	730	1,150
1,300,000	770	1,220
1,400,000	810	1,290
1,500,000	850	1,360
1,600,000	890	1,430
1,700,000	930	1,490
1,800,000	970	1 550
1,900,000	1,010	1,610
2,000,000	1,050	1,670

The lower limit is specified for rubber-covered wires to prevent gradual deterioration of the high insulations by the heat of the wires, but not from fear of igniting the insulation. The question of drop is not taken into consideration in the above tables.

The carrying capacity of sixteen and eighteen wire is given, but no smaller than fourteen is to be used, except as allowed under Rules 24 *u* and 40 *c*.

17. Switches, Cut-outs, Circuit Breakers, Etc.—

(*For construction rules see Nos. 43, 44 and 45.*)

a. Must, whenever called for, unless otherwise provided (for exceptions see No. 8 *c* and No. 22 *c*), be so arranged that the cut-outs will protect, and the opening of the switch or circuit breaker will disconnect, all of the wires; that is, in a two-wire system the two wires, and in a three-wire system the three wires, must be protected by the cut-out and disconnected by the operation of the switch or circuit breaker.

b. Must not be placed in the immediate vicinity of easily ignitable stuff or where exposed to inflammable gases or dust or to flyings of combustible material.

c. Must, when exposed to dampness, either be inclosed in a waterproof box or mounted on porcelain knobs.

CONSTANT-CURRENT SYSTEMS.

Principally Series Arc Lighting.

18. Wires.—

(*See also Nos. 14, 15 and 16.*)

a. Must have an *approved* rubber insulating covering. (See No. 40 *a*.)

b. Must be arranged to enter and leave the building through an *approved* double-contact service switch (see No. 43), mounted in a non-combustible case, kept free from moisture, and easy of access to police or firemen. So-called "snap switches" must not be used on high-potential circuits.

c. Must always be in plain sight, and never incased, except when *required* by the Inspection Department having jurisdiction.

d. Must be supported on glass or porcelain insulators, which separate the wire at least one inch from the surface wired over, and must be kept *rigidly* at least eight inches from each other, except within the structure of lamps, on hanger-boards, in cut-out boxes, or like places, where a less distance is necessary.

e. Must on side walls, be protected from mechanical injury by a substantial boxing, retaining an air space of one inch around the conductors, closed at the top (the wires passing through bushed holes), and extending not less than seven feet from the floor. When crossing floor timbers in cellars or in rooms, where they might be exposed to injury, wires must be attached by their insulating supports to the under side of a wooden strip not less than one-half an inch in thickness.

19. Arc Lamps.—

(*For construction rules, see No. 49.*)

a. Must be carefully isolated from inflammable material.

b. Must be provided at all times with a glass globe surrounding the arc, securely fastened upon a closed base. No broken or cracked globes to be used.

c. Must be provided with a wire netting (having a mesh not exceeding one and one-quarter inches) around the globe, and an *approved* spark arrester (see No. 50), when readily inflammable material is in the vicinity of the lamps, to prevent escape of sparks, melted copper or carbon. It is recommended that plain carbons, not copper-plated, be used for lamps in such places.

Arc lamps, when used in places where they are exposed to flyings of easily inflammable material, should have the carbons inclosed completely in a globe in such manner as to avoid the necessity for spark arresters.

For the present, globes and spark arresters will not be required on so-called "inverted arc" lamps, but this type of lamp must not be used where exposed to flyings of easily inflammable materials.

d. Where hanger boards (see No. 48) are not used, lamps must be hung from insulating supports other than their conductors.

20. Incandescent Lamps in Series Circuits.—

a. Must have the conductors installed as provided in Rule No. 18, and each lamp must be provided with an automatic cut-out.

b. Must have each lamp suspended from a hanger-board by means of a rigid tube.

c. No electro-magnetic device for switches and no system of multiple-series or series-multiple lighting will be approved.

d. Under no circumstances can they be attached to gas fixtures.

CONSTANT-POTENTIAL SYSTEMS.

General Rules—All Voltages.

21. Automatic Cut-Outs (*Fuses and Circuit Breakers.*)

(*See No. 17, and for construction, Nos. 44 and 45.*)

a. Must be placed on all service wires, either overhead or underground, as near as possible to the point where they enter the building and inside the walls, and arranged to cut off the entire current from the building.

Where the switch required by Rule No. 22 is inside the building, the cut-out required by this section must be placed so as to protect it.

b. Must be placed at every point where a change is made in the size of wire [unless the cut-out in the larger wire will protect the smaller. (See No. 16)].

c. Must be in plain sight, or inclosed in an *approved* box (see No 46), and readily accessible. They must not be placed in the canopies or shells of fixtures.

d. Must be so placed that no set of incandescent lamps, whether grouped on one fixture or several fixtures or pendants, requiring a current of more than six amperes shall be dependent upon one cut-out. Special permission may be given in writing by the Inspection Department having jurisdiction for departure from this rule in case of large chandeliers.

e. Must be provided with fuses the rated capacity of which does not exceed the allowable carrying capacity of the wire, and, when circuit breakers are used, they must not be set more than about thirty per cent above the allowable carrying capacity of the wire, unless a fusible cut-out is also installed in the circuit (see No. 16).

22. Switches.—

(*See No. 17, and for construction, No. 43*)

a. Must be placed on all service wires, either overhead or underground, in a readily accessible place, as near as possible to the point where the wires enter the building, and arranged to cut off the entire current.

b. Must always be placed in dry, accessible places, and be grouped as far as possible. Knife switches must be so placed that gravity will tend to open rather than to close the switch.

c. Must not be single-pole, except when the circuits which they control supply not more than six 16 candle-power lamps or their equivalent.

d. Where gangs of flush switches are used, whether with conduit systems or not, the switches must be inclosed in boxes constructed of or lined with fire resisting material. Where two or more switches are placed under one plate, the box must have a separate compartment for each switch. No push buttons for bells, gas lighting circuits or the like shall be placed in the same wall plate with switches controlling electric light or power wiring.

23. Electric Heaters.

a. Must, if stationary, be placed in a safe situation, isolated from inflammable materials and be treated as sources of heat.

b. Must each have a cut-out and *indicating* switch (see No. 17 *a*).

c. Must have the attachments of feed wires to the heaters in plain sight, easily accessible and protected from interference, accidental or otherwise.

d. The flexible conductors for portable apparatus, such as irons, etc., must have an *approved* insulating covering (see No. 40 *c*, 3).

e. Must each be provided with name plate, giving the maker's name and the normal capacity in volts and amperes.

LOW-POTENTIAL SYSTEMS.

300 VOLTS OR LESS.

Any circuit attached to any machine, or combination of machines, which develops a difference of potential, between any two wires, of over ten volts and less than 300 volts, shall be considered as a low-potential circuit, and as coming under the class, unless an approved transforming device is used, which cuts the difference of potential down to ten volts or less. The primary circuit not to exceed a potential of 3,000 volts.

24. Wires.—

GENERAL RULES.

(*See also Nos. 14, 15 and 16.*)

a. Must not be laid in plaster, cement or similar finish.

b. Must never be fastened with staples.

c. Must not be fished for any great distance, and only in places where the inspector can satisfy himself that the rules have been complied with.

d. Twin wires must never be used, except in conduits, or where flexible conductors are necessary.

e. Must be protected on side walls from mechanical injury. When crossing floor timbers in cellars or in rooms, where they might be exposed to injury, wires must be attached by their insulating supports to the under side of a wooden strip, not less than one-half inch in thickness, and not less than three inches in width.

Suitable protection on side walls may be secured by a substantial boxing, retaining an air space of one inch around the conductor, closed at the top (the wires passing through bushed holes), and extending not less than five feet from the floor; or by an iron-armored or metal-sheathed insulating conduit sufficiently strong to withstand the strain it will be subjected to; or plain metal pipe, lined with insulating tubing, which must extend one-half inch beyond the end of the metal tube.

The pipe must extend not less than five feet above the floor, and may extend through the floor in place of a floor bushing.

If iron pipes are used with alternating currents, the two or more wires of a circuit *must* be placed in the same conduit. In this case the insulation of each wire must be re-inforced by a tough conduit tubing projecting beyond the ends of the iron pipe at least two inches.

f. When run immediately under roofs, or in proximity to water tanks or pipes, will be considered as exposed to moisture.

SPECIAL RULES.

For Open Work *(In dry places)*:

g. Must have an *approved* rubber or weatherproof insulation. (See No. 40 *a* and *b*.)

h. Must be rigidly supported on non-combustible, non-absorptive insulators, which separate the wire at least one-half inch from the surface wired over, and they must be kept apart at least two and one half inches.

Rigid supporting requires under ordinary conditions, where wiring along flat surfaces, supports at least every four and one-half feet. If the wires are liable to be disturbed, the distance between supports should be shortened. In buildings of mill construction, mains of No. 8 B. & S. wire or over, where not liable to be disturbed, may be separated about four inches, and run from timber to timber, not breaking around, and may be supported at each timber only.

This rule will not be interpreted to forbid the placing of neutral of a three-wire system in the centre of a three-wire cleat, provided the outside wires are separated two and one-half inches.

In damp places, such as Breweries, Packing Houses, Stables, Dye Houses, Paper or Pulp Mills, or buildings specially liable to moisture or acid or other fumes liable to injure the wires or their insulation, except where used for pendants:

i. Must have an *approved* rubber insulating covering (see No. 40 *a*).

j Must be rigidly supported on non-combustible, non-absorptive insulators which separate the wire at least one inch from the surface wired over, and they must be kept apart at least two and one-half inches.

Rigid supporting requires under ordinary conditions, where wiring over flat surfaces, supports at least every four and one-half feet. If the wires are liable to be disturbed, the distance between supports should be shortened. In buildings of mill construction, mains of No. 8 B. & S. wire or over, where not liable to be disturbed, may be separated about four inches and run from timber to timber, not breaking around, and may be supported at each timber only.

k. Must have no joints or splices.

For Molding Work:

l. Must have *approved* rubber insulating covering (see No. 40 *a*).

m. Must never be placed in moulding in concealed or damp places.

For Conduit Work:

n. Must have an *approved* rubber insulating covering (see No. 40 *e*).

The use of concentric wire (see No. 40 *e*) is recommended in preference to twin conductors.

o Must not be drawn in until all mechanical work on the building has been, as far as possible, completed.

p. Must not have wires of different circuits drawn in the same conduit.

q. Must, for alternating systems, have the two or more wires of a circuit drawn in the same conduit.

It is advised that this be done for direct-current system also, so that they may be changed to alternating systems at any time, induction troubles preventing such a change unless this construction is followed.

For so-called Concealed Work:

r. Must have an *approved* rubber insulating covering (see No. 40 *a*).

s. Must be rigidly supported on non-combustible, non-absorptive insulators which separate the wire at least one inch from the surface wired over, and must be kept at least ten inches apart, and, when possible, should be run singly on separate timbers or studding

Rigid supporting requires under ordinary conditions, where wiring along flat surfaces, supports at least every four and one-half feet. If the wires are liable to be disturbed, the distance between supports should be shortened.

t. When from the nature of the case it is impossible to place concealed wiring on non-combustible insulating supports of glass or porcelain, the wires if not exposed to moisture, may be fished on the loop system if incased throughout in approved continuous flexible tubing or conduit. (See page 45.)

For Fixture Work:

u. Must have an *approved* rubber insulating covering (see No. 40 *d*), and shall not be less in size than No. 18, B & S.

v. Supply conductors, and especially the splices to fixture wires, must be kept clear of the grounded part of gas pipes, and, where shells are used, the latter must be constructed in a manner affording sufficient area to allow this requirement.

w. Must, when fixtures are wired outside, be so secured as not to be cut or abraded by the pressure of the fastenings or motion of the fixture.

25. Interior Conduits.—

(*See also Nos. 24 n to q, and 41.*)

The object of a tube or conduit is to facilitate the insertion or extraction of the conductors to protect them from mechanical injury and as far as possible, from moisture. Tubes or conduits are to be considered merely as raceways, and are not to be relied upon for insulation between wire and wire, or between the wire and the ground.

a. Must be continuous from one junction box to another or to fixtures, and the conduit tube must properly enter all fittings.

b. Must be first installed as a complete conduit system, without the conductors.

c. Conduits must extend at least one-half inch beyond the finished surface of walls or ceilings, except that, if the end is threaded and a coupling screwed on, the conduit may be left flush with the surface, and the coupling may be removed when work on building is completed

d. Must, after conductors are introduced, have all outlets plugged with special wood or fibrous plugs, made in parts, and the outlet then sealed with *approved* compound. Joints must be made airtight and moisture proof.

e. Must have the metal of the conduit permanently and effectually grounded.

26. Fixtures.—

(*See also No. 24 u to w.*)

a. Must, when supported from the gas piping of a building, be insulated from the gas pipe system by means of *approved* insulating joints (see No. 51) placed as close as possible to the ceiling.

It is recommended that the gas outlet pipe be protected above the insulating joint by a non-combustible, non-absorptive insulating tube, having a flange at the lower end where it comes in contact with the insulating joint; and that, where outlet tubes are used, they be of sufficient length to extend below the insulating joint, and that they be so secured that they will not be pushed back when the canopy is put in place. Where iron ceilings are used, care must be taken to see that the canopy is thoroughly and permanently insulated from the ceiling.

b. Must have all burs, or fins, removed before the conductors are drawn into the fixture.

c. The tendency to condensation within the pipes should be guarded against by sealing the upper end of the fixture.

d. No combination fixture in which the conductors are concealed in a space less than one-fourth inch between the inside pipe and the outside casing will be approved.

e. Must be tested for "contacts" between conductors and fixtures, for "short circuits" and for ground connections before it is connected to its supply conductors.

f. Ceiling blocks of fixtures should be made of insulating material; if not, the wires in passing through the plate must be surrounded with non-combustible, non-absorptive, insulating material, such as glass or porcelain.

27. Sockets.—

(*For construction rules see No 47.*)

a. In rooms where inflammable gases may exist, the incandescent lamp and socket must be inclosed in a vapor-tight globe, and supported on a pipe-hanger, wired with approved rubber-covered wire (see No. 40 *a*) soldered directly to the circuit.

b. In damp or wet places, or over specially inflammable stuff, waterproof sockets must be used.

When waterproof sockets are used, they should be hung by separate stranded rubber-covered wires, not smaller than No. 14 B. & S., which should preferably be twisted together when the drop is over three feet. These wires should be soldered direct to the circuit wires, but supported independently of them.

28. Flexible Cord.—

a. Must have an *approved* insulation and covering. (See No. 40 *c.*)

b. Must not be used as a support for clusters.

c. Must not be used except for pendants, wiring of fixtures and portable lamps or motors.

d. Must not be used in show windows.

e. Must be protected by insulating bushings where the cord enters the socket.

f. Must be so suspended that the entire weight of the socket and lamp will be borne by knots under the bushing in the socket, and above the point where the cord comes through the ceiling block or rosette, in order that the strain may be taken from the joints and binding screws.

29. Arc Lights on Low-Potential Circuits.—

a. Must have a cut-out (see No. 17 *a*) for each lamp or each series of lamps.

The branch conductors should have a carrying capacity about fifty per cent. in excess of the normal current required by the lamp to provide for heavy current required when lamp is started or when carbons become stuck without over-fusing the wires.

b. Must only be furnished with such resistances or regulators as are inclosed in non-combustible material, such resistances being treated as sources of heat. Incandescent lamps must not be used for resistance devices.

c. Must be supplied with globes and protected by spark arresters and wire netting around globe, as in the case of arc lights on high-potential circuits. (See Nos. 19 and 50.)

30. Economy Coils.—

a Economy and compensator coils for arc lamps must be mounted on non-combustible, non-absorptive insulating supports, such as glass or porcelain, allowing an air space of at least one inch between frame and support and in general to be treated like sources of heat.

31. Decorative Series Lamps.—

a Incandescent lamps run in series shall not be used for decorative purposes inside of buildings, except by special permission in writing from the Inspection Department having jurisdiction.

HIGH-POTENTIAL SYSTEMS.

300 TO 3,000 VOLTS.

Any circuit attached to any machine, or combination of machines, which develops a difference of potential, between any two wires, of over 300 volts and less than 3,000 volts, shall be considered as a high potential circuit, and as coming under that class, unless an approved transforming device is used, which cuts the difference of potential down to 300 volts or less.

32. Wires.—

(*See also Nos. 14, 15 and 16.*)

a. Must have an *approved* rubber insulating covering. (See No. 40 *a.*)

b. Must be always in plain sight and never incased, except where required by the Inspection Department having jurisdiction.

c. Must be rigidly supported on glass or porcelain insulators, which raise the wire at least one inch from the surface wired over, and must be kept apart at least four inches for voltages up to 750 and at least eight inches for voltages over 750

Rigid supporting requires under ordinary conditions, where wiring along flat surfaces, supports at least about every four and one-half feet.

If the wires are unusually liable to be disturbed, the distance between supports should be shortened.

In buildings of mill construction, mains of No. 8 B. & S. wire or over, where not liable to be disturbed, may be separated about six inches for voltages up to 750 and about ten inches for voltages above 750; and run from timber to timber, not breaking around, and may be supported at each timber only.

d. Must be protected on side walls from mechanical injury by a substantial boxing, retaining an air space of one inch around the conductors, closed at the top (the wires passing through the bushed holes) and extending not less than seven feet from the floor. When crossing floor timbers, in cellars or in rooms, where they might be exposed to injury, wires must be attached by their insulating supports to the under side of a wooden strip not less than one-half an inch in thickness.

33. Transformers (*When permitted inside buildings, see No. 13*).—

(*For construction rules, see No. 54.*)

a. Must be located at a point as near as possible to that at which the primary wires enter the building.

b. Must be placed in an inclosure constructed of or lined with fire-resisting material; the inclosure to be used only for this purpose, and to be kept securely locked and access to the same allowed only to responsible persons.

c. Must be effectually insulated from the ground and the inclosure in which they are placed must be practically air tight, except that it shall be thoroughly ventilated to the outdoor air, if possible, through a chimney or flue. There should be at least six inches air space on all sides of the transformer.

34. Car Wiring.—

a. Must be always run out of reach of the passengers, and must have an *approved* rubber insulating covering. (See No. 40 *a.*)

35. Car Houses.—

a. Must have the trolley wires securely supported on insulating hangers.

b. Must have the trolley hangers placed at such a distance apart that, in case of a break in the trolley wire, contact can not be made with the floor.

c. Must have cut-out switch located at a proper place outside of the building, so that all trolley circuits in the building can be cut out at one point, and line circuit breakers must be installed, so that when this cut-out switch is open the trolley wire will be dead at all points within 100 feet of the building. The current must be cut out of the building wherever the same is not in use or the road not in operation.

d. Must have all lamps and stationary motors installed in such a way that one main switch can control the whole of each installation—lighting or power—independently of main feeder-switch. No portable incandescent lamps or twin wire allowed, except that portable incandescent lamps may be used in the pits connections to be made by two *approved* rubber-covered flexible wires (see No. 40 *a*), properly protected against mechanical injury; the circuit to be controlled by a switch placed outside of the pit.

e. Must have all wiring and apparatus installed in accordance with rules under Class "C" for constant potential systems.

f. Must not have any system of feeder distribution centering in the building.

g. Must have the rails bonded at each joint with not less than No. 2 B. & S. annealed copper wire; also a supplementary wire to be run for each track.

h Must not have cars left with trolley in electrical connection with the trolley wire.

36. Lighting and Power from Railway Wires.—

a. **Must not be permitted, under any pretense, in the same circuit with trolley wires with a ground return, except in electric railway cars, electric car houses, and their power stations, nor shall the same dynamo be used for both purposes.**

37. Series Lamps.—

a. No system of multiple series or series-multiple for light or power will be approved.

b. Under no circumstances can lamps be attached to gas fixtures.

EXTRA HIGH-POTENTIAL SYSTEMS.

Over 3,000 Volts.

Any circuit attached to any machine or combination of machines, which develops a difference of potential, between any two wires, of over 3,000 volts, shall be considered as an extra high potential circuit, and as coming under that class, unless an approved transforming device is used, which cuts the difference of potential down to 3,000 volts or less.

38. Primary Wires.—

Must not be brought into or over buildings, except power and sub-stations.

39. Secondary Wires.—

a, Must be installed under rules for high-potential systems, when their immediate primary wires carry a current at a potential of over 3,000 volts.

The high line insulation required for extra high-potential current tends to make the insulation resistance between primary and secondary coils of transformers a comparatively weak point, and lightning discharges would be apt to take this path to the earth. With the present means of protection against transformer break downs and the consequent liability of secondary wiring being subjected to the strain of the primary current, it is not deemed advisable to permit a primary current with a potential of over 3,000 volts without an intermediate step-down transformer. The presence of wires carrying a current at a potential of over 3,000 volts in the streets of cities and towns is also considered as increasing the fire hazard.

Class D.

FITTINGS, MATERIALS AND DETAILS OF CONSTRUCTION.

All Systems and Voltages.

40. Wire Insulation.—

a. Rubber Covered.—The insulating covering must be solid, at least three sixty-fourths of an inch in thickness and covered with a substantial braid. It must not readily carry fire, must show an insulating resistance of one megohm per mile after two weeks' submersion in water at seventy degrees Fahrenheit and three days' submersion in lime water, and after three minutes' electrification with 550 volts. (See page 44.)

b. Weatherproof.—The insulating covering must not support combustion, must resist abrasion, must be at least one-sixteenth of an inch in thickness, and thoroughly impregnated with a moisture repellent

c. Flexible Cord.—Must be made of two stranded conductors, each having a carrying capacity equivalent to not less than a No. 16 B. & S. wire, and each covered by an *approved* insulation, and protected by a slow-burning, tough-braided outer covering.

1. Insulation for *pendants* under this rule must be moisture and flame proof.

2. Insulation for *cords used for all other purposes*, including portable lamps and motors, must be solid, at least one thirty-second of an inch in thickness, and must show an insulation resistance between conductors and between either conductor and the ground, at least one megohm per mile after one week's *submersion* in water at seventy degrees Fahrenheit, and after three minutes' electrification, with 550 volts.

3. The flexible conductors for *portable heating apparatus*, such as irons, etc., must have an insulation that will not be injured by the heat, such as asbestos, which must be protected from mechanical injury by an outer, substantial, braided covering, and so arranged that mechanical strain will not be borne by the electrical connection.

d. Fixture Wire.—Must have a solid insulation, with a slow-burning, tough outer covering, the whole to be at least one thirty-second of an inch in thickness, and show an insulation resistance between conductors, and between either conductor and the ground, of at least one megohm per mile, after one week's submersion in water at seventy degrees Fahrenheit, and after three minutes' electrification, with 550 volts.

e. Conduit Wire.—Must comply with the following specifications:

1. *For insulated metal conduits* single wires and twin conductors must comply with Section *a*, of this rule.

Concentric wire must have a braided covering between the outer conductor and the insulation of the inner conductor, and, in addition, must comply with Section *a*, of this rule.

2. *For non-insulated metal conduits* single wires and twin conductors must comply with Section *a*, of this rule; and, in addition, have a second outer fibrous covering, at least one thirty-second of an inch in thickness, and sufficiently tenacious to withstand the abrasion of being hauled through the metal conduit

Concentric conductors must have a braided covering between the outer conductor and the insulation of the inner conductor, and comply with Section *a*, of this rule; and, in addition must have a second outer fibrous covering at least one thirty-second of an inch in thickness, and sufficiently tenacious to withstand the abrasion of being hauled through the metal conduit.

41. Interior Conduits.—

(*For wiring rules, see Nos. 24 and 25.*)

a. Each length of conduit, whether insulated or uninsulated, must have the maker's name or initials stamped in the metal or attached thereto in a satisfactory manner, so that the inspectors can readily see the same.

Insulated Metal Conduits:

b. The metal covering, or pipe, must be at least equal in thickness, or of equal strength to resist penetration by nails, etc., as the ordinary commercial form of gas pipe of same size.

c. Must not be seriously affected externally by burning out a wire inside the tube when the iron pipe is connected to one side of the circuit.

d. Must have the insulating lining firmly secured to the pipe.

e. The insulating lining must not crack or break when a length of the conduit is uniformly bent at a temperature of 212 degrees Fahrenheit to an angle of ninety degrees, with a curve having a radius of fifteen inches, for pipes of one inch and less, and fifteen times the diameter of pipe for larger pipes.

f. The insulating lining must not soften injuriously at a temperature below 212 degrees Fahrenheit, and must leave water, in which it is boiled, practically neutral.

g. The insulating lining must be at least one thirty-second of an inch in thickness, and the materials of which it is composed must be of such a nature as will not have a deteriorating effect on the insulation of the conductor, and be sufficiently tough and tenacious to withstand the abrasion test of drawing in and out of the same long lengths of conductors.

h. The insulating lining must not be mechanically weak after three days' submersion in water, and, when removed from the pipe entire, must not absorb more than ten per cent. of its weight of water during 100 hours of submersion.

i. All elbows must be made for the purpose, and not bent from lengths of pipe. The radius of the curve of the inner edge of any elbow not to be less than three and one-half inches. Must have not more than the equivalent of four quarter bends from outlet to outlet, the bends at the outlets not being counted.

Uninsulated Metal Conduits:

j. Plain iron or steel pipes of equal thickness, or of equal strength, to resist penetration of nails, etc., as the ordinary commercial form of gas pipe of the same size, may be used as conduits, provided their interior surfaces are smooth and free from burs ; pipe to be galvanized, or the interior surfaces coated or enameled, to prevent oxidization, with some substance which will not soften so as to become sticky and prevent wire from being withdrawn from the pipe.

k. All elbows must be made for the purpose, and not bent from lengths of pipe. The radius of the curve of the inner edge of any elbow not to be less than three and one-half inches. Must have not more than the equivalent of four quarter bends from outlet to outlet, the bends at the outlets not being counted.

42. Wooden Mouldings.—

(*For wiring rules see No. 24.*)

a. Must have, both outside and inside, at least two coats of waterproof paint, or be impregnated with a moisture repellent.

b. Must be made of two pieces, a backing and capping so constructed as to thoroughly incase the wire, and provide a one-half inch tongue between the conductors, and a solid backing, which, under grooves, shall not be less than three-eighths of an inch in thickness, and must afford suitable protection from abrasion.

It is recommended that only hardwood moulding be used.

43. Switches.—

(*See Nos. 17 and 22.*)

a. Must be mounted on non-combusiible, non-absorptive, insulating bases, such as slate or porcelain.

b. Must have carrying capacity sufficient to prevent undue heating.

c. Must, when used for service switches, indicate, on inspection, whether the current be "on" or "off."

d. Must be plainly marked whether it will always be visible, with the name of the maker and the current and voltage for which the switch is designed.

e. Must, for constant potential systems, operate successfully at fifty per cent. overload in amperes, with twenty-five per cent. excess voltage under the most severe conditions they are liable to meet with in practice.

f. Must, for constant potential systems, have a firm and secure contact ; must make and break readily, and not stop when motion has once been imparted by the handle.

g. Must, for constant current systems, close the main circuit and disconnect the branch wires when turned "off"; must be so constructed that they shall be automatic in action, not stopping between points when started, and must prevent an arc between the points under all circumstances. They must indicate, upon inspection, whether the current be "on" or "off."

44. Cut-Outs and Circuit Breakers.—

(*For installation rules, see Nos. 17 and 21.*)

a. Must be supported on bases of non-combustible, non-absorptive insulating material.

b. Cut-outs must be provided with covers, when not arranged in approved cabinets, so as to obviate any danger of the melted fuse metal coming in contact with any substance which might be ignited thereby.

c. Cut-outs must operate successfully, under the most severe conditions they are liable to meet with in practice, on short circuits with fuses rated at 50 per cent. above and with a voltage 25 per cent. above the current and voltage for which they are designed.

d. Circuit-breakers must operate successfully, under the most severe conditions they are liable to meet with in practice, on short circuits when set at fifty per cent. above the current, and with a voltage twenty-five per cent. above that for which they are designed.

e. Must be plainly marked where it will always be visible, with the name of the maker, and current and voltage for which the device is designed.

45. Fuses.—

(*For installation rules, see Nos. 17 and 21.*)

a. Must have contact surfaces or tips of harder metal having perfect electrical connection with the fusible part of the strip.

b. Must be stamped with about eighty per cent. of the maximum current they can carry indefinitely, thus allowing about twenty-five per cent. overload before fuse melts.

With naked open fuses, of ordinary shapes and not over 500 amperes capacity, the *maximum* current which will melt them in about five minutes may be safely taken as the melting point, as the fuse practically reaches its maximum temperature in this time. With larger fuses a longer time is necessary.

Inclosed fuses where the fuse is often in contact with substances having good conductivity to heat, and often of considerable volume, require a much longer time to reach a maximum temperature on account of the surrounding material which heats up slowly.

This data is given to facilitate testing.

c. Fuse terminals must be stamped with the maker's name, initials, or some known trademark.

46. Cut-out Cabinets.—

a. Must be so constructed, and cut-outs so arranged, as to obviate any danger of the melted fuse metal coming in contact with any substance which might be ignited thereby.

A suitable box can be made of marble, slate or wood, strongly put together, the door to close against a rabbet so as to be perfectly dust tight, and it should be hung on strong hinges and held close by a strong hook or catch. If the box is wood, the inside should be lined with sheets of asbestos board about one-sixteenth of an inch in thickness, neatly put on and firmly secured in place by shellac and tacks. The wires should enter through holes bushed with porcelain bushings; the bushings tightly fitting the holes in the box, and the wires tightly fitting the bushings (using tape to build up the wire, if necessary) so as to keep out the dust.

47. Sockets.—

(*See No. 27.*)

a. No portion of the lamp socket, or lamp base, exposed to contact with outside objects, must be allowed to come into electrical contact with either conductor.

b Must, when provided with keys, comply with the requirements for switches. (See No. 43.)

48. Hanger-Boards.—

a. Hanger-boards must be so constructed that all wires and current carrying devices thereon shall be exposed to view and thoroughly insulated by being mounted on a non-combustible, non-absorptive insulating substance. All switches attached to the same must be so constructed that they shall be automatic in their action, cutting off both poles to the lamp, not stopping between points when started and preventing an arc between points under all circumstances.

49. Arc Lamps.—

(*For installation rules, see No. 19.*)

a. Must be provided with reliable stops to prevent carbons from falling out in case the clamps become loose.

b. Must be carefully insulated from the circuit in all their exposed parts.

c. Must, for constant current systems, be provided with an *approved* hand switch, also an automatic switch that will shunt the current around the carbons, should they fail to feed properly.

The hand-switch to be approved if placed anywhere except on the lamp itself, must comply with requirements for switches on hanger-boards as laid down in Rule 48.

50. Spark Arresters.—

(*See No. 19 c.*)

a. Spark arresters must so close the upper orifice of the globe that it will be impossible for any sparks, thrown off by the carbons, to escape.

51. Insulating Joints.—

(*See No. 26 a.*)

a. Must be entirely made of material that will resist the action of illuminating gases, and will not give way or soften under the heat of an ordinary gas flame, or leak under a moderate pressure. They shall be so arranged that a deposit of moisture will not destroy the insulating effect, and shall have an insulating resistance of at least 250,000 ohms between the gas pipe attachments, and be sufficiently strong to resist the strain they will be liable to be subjected to in being installed.

b. Insulating joints having soft rubber in their construction will not be approved.

52. Resistance Boxes and Equalizers.—

(*For Installation rules, see No. 4.*)

a. Must be equipped with metal, or with other non-combustible frames.

The word "frame" in this section relates to the entire case and surroundings of the rheostat, and not alone to the upholding supports.

53. Reactive Coils and Condensers.—

a. Reactive coils must be made of non-combustible material, mounted on non-cumbustible bases and treated, in general, like sources of heat.

b. Condensers must be treated like apparatus operating with equivalent voltage and currents They must have non-combustible cases and supports, and must be isolated from all combustible materials and, in general, treated like sources of heat.

54. Transformers.—

(*For installation rules, see Nos. 11 and 33.*)

a. Must not be placed in any but metallic or other non-combustible cases.

55. Lightning Arresters.—

(*For installation rules, see No. 5.*)

a. Must be mounted on non-combustible bases, and must be so constructed as not to maintain an arc after the discharge has passed, and must have no moving parts.

CLASS E.

MISCELLANEOUS.

56. Insulation Resistance.—

The wiring in any building must test free from grounds, *i. e*, the complete installation between conductors and between all conductors and the ground (not including attachments, sockets, receptacles, etc.) of not less than the following:

Up to	5 amperes	
"	10 "	4,000,000
"	25 "	2,000,000
"	50 "	800,000
"	100 "	400,000
"	200 "	200,000
"	400 "	100,000
"	800 "	50,000
"	1,600 " and over	25,000
		12,500

All cut-outs and safety devices in place in the above.

Where lamp sockets, receptacles and electroliers, etc., are connected, one-half of the above will be required.

57. Protection Against Foreign Currents.—

a. Where telephone, telegraph or other wires, connected with outside circuits, are bunched together within any building, or where inside wires are laid in conduits or ducts with electric light or power wires, the covering of such wires must be fire resisting, or else the wires must be inclosed in an air-tight tube or duct.

b. All aerial conductors and underground conductors, which are directly connected to aerial wires, connected with telephone, telegraph, district messenger, burglar alarm, watch-clock, electric-time and other similar instruments must be provided near the point of entrance to the building with some approved protective device which will operate to shunt the instruments in case of a dangerous rise of potential, and will open the circuit and arrest any abnormal current flow. Any conductor normally forming an innocuous circuit may become a source of fire hazard if crossed with another conductor charged with a relatively high pressure

Protectors must have a non-combustible insulating base, and the cover to be provided with a lock similar to the lock now placed on telephone apparatus or some equally secure fastening, and to be installed under the following requirements:

1. The protector to be located at the point where the wires enter the building, either immediately inside or outside of the same. If outside, the protector to be enclosed in a metallic, waterproof case.

2. If the protector is placed inside of building, the wires of the circuit from the support outside to the binding posts of the protector to be of such insulation as is approved for service wires of electric light and power (See No. 40 *a*) and the holes through the outer wall to be protected by bushing the same as required for electric light and power service wires.

3. The wire from the point of entrance to the protector to be run in accordance with rules for high-potential wires, *i. e.*, free of contact with building and supported on non-combustible insulators.

4. The ground wire shall be insulated, not smaller than No. 16 B. & S. gauge copper wire. This ground wire shall be kept at least three inches from all conductors, and shall never be secured by uninsulated, double-pointed tacks, and must be run in as straight a line as possible to the ground connection.

5. The ground wire shall be attached to a water pipe, if possible, otherwise may be attached to a gas pipe. The ground wire shall be carried to, and attached to, the pipe outside of the first joint or coupling inside the foundation walls, and the connection shall be made by soldering, if possible In the absence of other good ground, the ground shall be made by means of a metallic plate or a bunch of wires buried in a permanently moist earth.

58. Electric Gas Lighting.—

Where electric gas lighting is to be used on the same fixture with the electric light:

a. No part of the gas piping or fixture shall be in electric connection with the gas lighting circuit.

b. The wires used with the fixtures must have a non-inflammable insulation, or where concealed between the pipe and shell of the fixture, the insulation must be such as required for fixture wiring for the electric light.

c. The whole installation must test free from "grounds."

d. The two installations must test perfectly free from connection with each other.

59. Soldering Fluid.—

a. The following formula for soldering fluid is suggested:

Saturated solution of zinc chloride	5 parts.
Alcohol	4 parts.
Glycerine.	1 part.

CLASS F.

MARINE WORK.

60. Generators.—

a. Must be located in a dry place.

b. Must have their frames insulated from their bed-plates.

c. Must each be provided with a waterproof cover.

d. Must each be provided with a name plate, giving the maker's name, the capacity in voltage and amperes and normal speed in revolutions per minute.

61. Wires.—

a. Must have an *approved* insulating covering.

The insulation for all conductors, except for portables, to be approved, must be at least one-eighth inch in thickness and be covered with a substantial waterproof and flame-proof braid. The physical characteristics shall not be affected by any change in temperature up to 200 degrees Fahrenheit. After two weeks' submersion in salt water at 70 degrees Fahrenheit it must show an insulation resistance of one megohm per mile after three minutes' electrification, with 550 volts.

b. Must have no single wire larger than No. 12 B. & S. Wires to be stranded when greater carrying capacity is required. No single solid wire smaller than No. 14 B. & S., except in fixture wiring, to be used.

Stranded wires must be soldered before being fastened under clamps or binding screws, and when they have a conductivity greater than No. 10 B. & S. copper wire they must be soldered into lugs.

c. Must be supported in approved molding, except at switchboards and portables

Special permission may be given for deviation from this rule in dynamo rooms.

d. Must be bushed with hard rubber tubing one-eighth inch in thickness when passing through beams and non-water-tight bulkheads.

e. Must have, when passing through water-tight bulkheads and through all decks, a metallic stuffing tube lined with hard rubber. In case of deck tubes they shall be boxed near deck to prevent mechanical injury.

f. Splices or taps in conductors must be avoided as far as possible. Where it is necessary to make them, they must be so spliced or joined as to be both mechanically and electrically secure without solder. They must then be soldered, to insure preservation, covered with an insulating compound equal to the insulation of the wire, and further protected by a waterproof tape. The joint must then be coated or painted with a waterproof compound.

62. Portable Conductors.—

a Must be made of two stranded conductors, each having a carrying capacity equivalent to not less than No. 14 B. & S. wire, and each covered with an approved insulation and covering.

Where not exposed to moisture or severe mechanical injury, each stranded conductor must have a solid insulation at least one-thirty second of an inch in thickness, and must show an insulation resistance between conductors, and between either conductor and the ground, of at least one megohm per mile after one week's submersion in water at seventy degrees Fahrenheit and after three minutes' electrification, with 500 volts, and be protected by a slow-burning, tough-braided outer covering.

Where exposed to moisture and mechanical injury—as for use on decks, holds and fire rooms—each stranded conductor shall have a solid insulation, to be approved, of at least one-thirty-second of an inch in thickness and protected by a tough braid. The two conductors shall then be stranded together, using a jute filling. The whole shall then be covered with a layer of flax, either woven or braided, at least one-thirty-second of an inch in thickness, and treated with a non-inflammable, waterproof compound. After one week's submersion in water at seventy degrees Fahrenheit, with 550 volts and a three minutes' electrification, must show an insulation between the two conductors, or between either conductor and the ground of one megohm per mile.

63. Bell or other Wires.—

a. Shall never be run in same duct with lighting or power wires.

64. Table of Capacity of Wires.—

B. & S G.	Area Actual C. M.	No. of Strands.	Size of Strands B. & S. G.	Amperes.
19	1,288	—	—	—
18	1,624	—	—	3
17	2,048	—	—	—
16	2,583	—	—	6
15	3,257	—	—	—
14	4,107	—	—	12
12	6,530	—	—	17
—	9.016	7	19	21
—	11,368	7	18	25
—	14,336	7	17	30
—	18,081	7	16	35
—	22,709	7	15	40
—	30,856	19	18	50
—	38,912	19	17	60
—	49,077	19	16	70
—	60,088	37	18	85
—	75 776	37	17	100
—	99,064	61	18	120
—	124,928	61	17	145
—	157.563	61	16	170
—	198,677	61	15	200
—	250,527	61	14	235
—	296,387	91	15	270
—	373,737	91	14	320
—	413,639	127	15	340

When greater conducting area than that of 12 B. & S. G. is required, the conductor shall be stranded in a series of 7, 19, 37, 61, 91 or 127 wires, as may be required; the strand consisting of one central wire, the remainder laid around it concentrically, each layer to be twisted in the opposite direction from the preceding.

65. Switchboards.—

a. Must be made of non-combustible, non-absorptive, insulating material, such as marble or slate.

b. Must be kept free from moisture, and must be located so as to be accessible from all sides.

c. Must have a main switch, main cut-out and ammeter for each generator.

Must also have a voltmeter and ground detector.

d. Must have a cut-out and switch for each side of each circuit leading from board.

66. Resistance Boxes.—

a. Must be made of non-combustible material.

b. Must be located on a switchboard or away from combustible material. When not placed on switchboard they must be mounted on non-inflammable, non-absorbtive insulating material.

c. Must be so constructed as to allow sufficient ventilation for the uses to which they are put.

67. Switches.—

a. Must have non-combustible, non-absorptive, insulating bases.

b. Must operate successfully at fifty per cent. overload in amperes with twenty five per-cent. excess voltage under the most severe conditions they are liable to meet with in practice. and must be plainly marked where it will always be visible, with the name of the maker and the current and voltage for which the switch is designed.

c. Must be double-pole when circuits which they control supply more than six 16-candle-power lamps or their equivalent.

d. When exposed to dampness, they must be enclosed in a water-tight case.

68. Cut-outs.—

a. Must have non-combustible, non absorptive, insulating bases.

b. Must operate successfully under the most severe conditions they are liable to meet with in practice, on short circuit with fuse rated at fifty per cent. above, and with a voltage twenty-five per cent. above the current and voltage they are designed for, and must be plainly marked where they will always be visible with the name of the maker and current and voltage for which the device is designed.

c. Must be placed at every point where a change is made in the size of the wire (unless the cut-out in the larger wire will protect the smaller).

d. In places such as upper decks, holds, cargo spaces and fire rooms, a water-tight and fireproof cut-out may be used, connecting directly to mains when such cut-out supplies not more than six 16-candle power lamps or their equivalent.

e. When placed anywhere except on switchboards and certain places, as cargo spaces, holds, fire-rooms, etc., where it is impossible to run from centre of distribution, they shall be in a cabinet lined with fire-resisting material.

f. Except for motors, search-lights and diving lamps shall be so placed that no group of lamps, requiring a current of more than six amperes, shall ultimately be dependent upon one cut-out.

A single-pole covered cut-out may be placed in the moulding when same contains conductors supplying current for not more than two 16-candle-power lamps or their equivalent.

69. Fixtures.—

a. Shall be mounted on blocks made from well seasoned lumber treated with two coats of white lead or shellac.

b. Where exposed to dampness, the lamp must be surrounded by a vapor-proof globe.

c Where exposed to mechanical injury, the lamp must be surrounded by a globe protected by a stout wire guard.

d Shall be wired with same grade of insulation as portable conductors which are not exposed to moisture or mechanical injury.

70. Sockets.—

a. No portion of the lamp socket or lamp base exposed to contact with outside objects shall be allowed to come into electrical contact with either of the conductors.

71. Wooden Mouldings.—

a. Must be made of well seasoned lumber, and be treated inside and out with at least two coats of white lead or shellac.

b. Must be made of two pieces, a backing and a capping, so constructed as to thoroughly incase the wire and provide a one-half-inch tongue between the conductors and a solid backing which, under grooves, shall not be less than three-eighths inch in thickness.

c. Where moulding is run over rivets, beams, etc., a backing strip must first be put up and the moulding secured to this.

d. Capping must be secured by brass screws.

72. Motors.—

a. Must be wired under the same precautions as with a current of same volume and potential for lighting. The motor and resistance box must be protected by a double-pole cut-out and controlled by a double-pole switch, except in cases where one-quarter horse-power or less is used.

The leads or branch circuits should be designed to carry a current at least fifty per cent. greater than that required by the rated capacity of the motor to provide for the inevitable overloading of the motor at times.

b. Must be thoroughly insulated. Where possible, should be set on base frames made from filled, hard, dry wood and raised above surrounding deck. On hoists and winches they shall be insulated from bed-plates by hard rubber, fiber or similar insulating material.

c. Shall be covered with a waterproof cover when not in use.

d. Must each be provided with a name plate giving maker's name, the capacity in volts and amperes and the normal speed in revolutions per minute.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, September 29th, 1897.

The 118th meeting of the Institute was held this date, at 12 West 31st Street, and was called to order by President Crocker at 8.20 P. M.

The Secretary:—At the meeting of the Executive Committee of the Council, on September 15th, the following associate members were elected:

Name.	Address	Endorsed by.
Black Howard D.	Salesman, Blackall & Baldwin, 7 West 19th St.; P. O. Box 267 New York, N. Y.	S S. Wheeler. F. B. Crocker. Gano S. Dunn.
Blackall, Frederick, S.	Selling Agent, Crocker-Wheeler Electric Co., P. O. Box 267 New York; residence, Roselle, N. J.	S. S. Wheeler Gano S. Dunn. F. B. Crocker.
Graves, Chas. B.	Senior Student, Tufts College, Mass.; residence, Marblehead, Mass.	J. R. Lovejoy. Sidney B. Paine. C. D. Haskins.
Stout, George H.	Representative of Crocker-Wheeler Electric Co. and Walker Co., Box 73 Atlantic Highlands, N.J.	C. S. Bradley. T. J. Smith. S. S. Wheeler.

Total 4.

The President:—Gentlemen, as I appear here rather as an advocate than as a judge, it is proper that I should not preside at this meeting. It may be necessary for me to take part in the debate. My connection with this National Conference on Standard Electrical Rules ante-dated by more than a year my election to the presidency, and it was not practicable to sever that connection—certainly not before this meeting. Therefore I shall call upon Mr. Lieb, one of our Managers, to kindly take the chair.

Mr. Lieb then took the chair.

The Chairman:—We will begin the presentation of the matter that is to come before the meeting this evening by the reading of Dr. Crocker's report.

The Secretary read the following:

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

REPORT ON THE

"NATIONAL ELECTRICAL CODE."

The National Conference on Standard Electrical Rules met in New York City on March 18th and 19th, 1896. This body was composed of delegates representing the various Electrical, Insurance, Architectural and allied interests, and had for its object the adoption of one Electrical Code to take the place of the many conflicting Codes then in existence. Representatives of the principal electrical companies were invited to attend the Conference but it was decided at the meeting that these delegates should be made Associate Members and that the voting membership should be confined to the following Associations:

American Institute of Architects.
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.
American Society of Mechanical Engineers.
American Street Railway Association.
Factory Mutual Fire Insurance Companies.
National Association of Fire Engineers.
National Board of Fire Underwriters.
National Electric Light Association.
Underwriters' National Electric Association.

As a result of the labors of this Conference, acting in co-operation with the Underwriters' National Electric Association, a revised set of rules has been formulated to which the name "National Electrical Code" has been given, a copy of which is submitted herewith. This Code has already been adopted or approved by the following bodies:

Factory Mutual Fire Insurance Companies.
National Board of Fire Underwriters,
National Electric Light Association.
Underwriters' National Electric Association.
National Association of Fire Engineers.

The influence already exerted by the INSTITUTE in this matter has been most important; in fact, it is no exaggeration to say that the Conference would have failed to accomplish its object had the INSTITUTE held aloof from it. The representative of the INSTITUTE was appointed Chairman of the Committee on Code, which performed the actual work of revising the Rules. The New Code contains many amendments in regard to the technical requirements, and in form it has been entirely revised. The latter fact is particularly important, as previous codes had become a patch-work containing many repetitions and interpolations. This result alone is a sufficient reward for the labors of the Conference. It is not claimed that the Code is perfect, but it can be said that each word in it was carefully considered by a number of men representing the most diverse interests and points of view. If amendments are required in the future they can easily be made, the new arrangement of the Code being specially designed to enable this to be done without injury to its general form. In view of the very great advantages to be obtained by the general adoption of one uniform Code for the whole country; the fact that it has already been adopted by the most important bodies represented in the Conference, and in order to complete the powerful and beneficial influence which the INSTITUTE has already exerted in this matter, your delegate earnestly recommends that the INSTITUTE give its approval to the "National Electrical Code." This action need not be an adoption of the Code which would be in any way binding upon the individual members of the INSTITUTE. All that is necessary is that the INSTITUTE should approve the Code as representing uniformity and co-operative action. One of the most important functions that the INSTITUTE can possibly perform is the encouragement and securing of the very uniformity which this Code so well represents.

Respectfully submitted,

FRANCIS B. CROCKER,
Delegate.

NEW YORK, Sept. 15th, 1897.

THE CHAIRMAN:—Gentlemen, you have heard the report read by the Secretary in which this new code is submitted for your consideration, and I will now declare the discussion open. I think it might be well, and also as a recognition of the labors which he has bestowed on this subject, to ask Mr. William J. Hammer if he will kindly open the discussion.

MR. HAMMER:—I would rather have kept quiet just now and listened to others. I would like to say however, that when Dr. Crocker prepared his report as delegate from the INSTITUTE, there were only four names which appeared of associations which had already considered and adopted the National Electrical Code, and at that time I sent a letter to the official delegates of the other five associations to find out what action if any their associations had taken, and how soon they proposed to take action, in order that I might, perhaps, refer to it here. I at once heard from Captain Brophy that his association, that is the National Association of Fire Engineers, had unanimously adopted the code, and the notice was received in time to add it to the other four associations which had already adopted the code. I have this evening received a letter from the representative of the American Institute of Architects, whom I had seen personally and who assured me that the matter would come before the Executive Committee of his association, and he gave most positive assurance of its adoption by the American Institute of Architects. His letter, which I received this evening, says:

> "Your favor of the 23d received and contents noted. We did not succeed in getting a quorum to attend the last Executive Committee meeting of the American Institute of Architects; but our annual convention is to be held in Detroit next week, preceded by the Board of Directors, at which time action will be taken upon the National Code. I have written a report to the convention, and also to the Directors on the subject which I shall present at the meeting.
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> Yours very truly,
> Alfred Stone."

And I might say that I also received this afternoon a letter of similar import from Mr. Frank R. Ford, delegate of the American Street Railway Association, who is entirely in sympathy with this matter, and who has prepared his report for submission at the meeting of the American Street Railway Association in October, and from what we hear, there is every reason to expect that that association will adopt the National Electrical Code. We have also received a very strong assurance from the association under whose roof we are now assembled and who courteously extended the facilities of their house as the official headquarters of the National Conference on Standard Electrical Rules. It was here that we held our meeting and had our discussions. It was here that the Code Committee met, and we as an association have received very great courtesies from the American Society of Mechanical Engineers, and from what I personally have heard and from what Dr. Crocker tells me, there is practically no question but that that association will approve the National Electrical Code.

THE CHAIRMAN:—We would be glad to hear from Mr. Sachs, who, I understand, is prepared to discuss the subject under consideration.

MR. JOSEPH SACHS:—I did not come prepared to open the discussion upon this subject. Those who were more intimately connected with the formulation of the code might more properly begin. I would like to come in at the end. There are various sections of this new code which admit of discussion. The effect of various changes that have been made in the new, as distinguished from the old code, might be discussed and some of the new features criticised, others perhaps lauded. Amongst the novelties, for instance, in this new code, is the permission given to use plain pipe and the recommendation, if it may be so called, of automatic electro-magnetic circuit-breaking devices. These features stand out very distinctly, although there are also quite a number of others.

DR. A. E. KENNELLY:—I think that the INSTITUTE is to be congratulated upon the report that has been presented to it this evening and upon the National Electric Code as it appears before us in print. We all know how much confusion has existed in the past from the co-existence of a variety of different rules not merely in different parts of the country, but in different organizations of the same city. I cannot help thinking that the fusion of all pre-existing codes into a single code, if we can secure it, is so highly desirable, that we should do all in our power to bring it about. No doubt many of us may have our own ideas as to possible improvements in this code, but it seems to me that the advantage of national uniformity outweighs any objections that can be urged against any particular rules. I may be permitted to say that at the time when the INSTITUTE was invited to enter this National Conference, I had fears that such a conference might bring the INSTITUTE into unpleasant relations with commercial associations, and that bad feeling and dissension in the

INSTITUTE might ensue. I am glad to find that my fears have apparently been groundless, owing in large measure no doubt to tact and care of the officer delegated to represent the INSTITUTE at the Conference, and I think we may be gratified by the results which seems to have been reached, namely the agreement of so many conflicting interests and so much vested and uninvested capital upon a single set of rules. I would move sir, that the report here presented be adopted by the INSTITUTE, be spread upon the minutes, and that the National Electrical Code as it is here presented in pamphlet form, be printed in the TRANSACTIONS.

MR. GANO S. DUNN :—Mr. Chairman—I rise to second the motion most heartily. As Dr. Kennelly has said, there are a number of things in the code which do not agree with the ideas of all of us. Being connected with the manufacture of electrical machinery, there are several items that I would change, but, for the same reason, I appreciate the value of the code because of its uniformity, and I cannot fully express how much I feel that it is desirable for this INSTITUTE to approve this code and thereby assist in supporting it.

THE CHAIRMAN :—Gentlemen, you have heard the motion made by Dr. Kennelly that the report of Dr. Crocker be received, and the code accompanying it be spread upon the minutes and receive the formal approval of the INSTITUTE, and you have also heard the seconding of that motion by Mr. Gano S. Dunn. We will continue the discussion, if it is your pleasure, before the motion is put to a formal vote.

MR. C. O. MAILLOUX :—I note that in the latter portion of Dr. Crocker's report he says that "This action need not be an adoption of the code which would be in any manner binding upon the individual members of the INSTITUTE. All that is necessary is that the INSTITUTE should approve the code as representing uniformity and co-operative action." Now, gentlemen, I think that that is a very sensible way to put it, and I think that all our action in this matter ought to be bounded and limited by these two sentences. That is all that the report asks, and I think that is all that we should give to it. It asks merely that the code be approved as an evidence and a step of progress in the direction of uniformity and co-operative action. In adopting it in that way and in that form we are not committing the INSTITUTE or its members to any tacit approval of any of its contents, excepting in-so-far as the said contents may recommend themselves to individual judgment, and may accord with personal experience as to the requirements which the particular individual in question may possess. I regret that I have not been able to study carefully the rules. I have just lately returned from abroad and I found naturally a great deal to do, and two new sets of rules, on my hands, one issued by the City Fire Department and the new one by the National Board of Fire Underwriters. I have looked into the two sets only in-so-far as it has been necessary for me to do so to guide me in carrying out the work which I have had in hand. Consequently, I cannot say that I have intimate enough knowledge of the two sets of rules to be able to speak very exhaustively or to make any exhaustive commentary or criticism on either of them. I have been struck however with the thoroughness with which the City Fire Department rules have been worked up. I could not help noticing that they had gone into a good many points which are still left obscure in the other rules, and that they rationalized certain points which had been always treated in a somewhat arbitrary and empirical manner in all previous rules. I may note, for instance, the fact of making the insulation resistance required, a function of the working pressure. I may also note the fact that the separation between conductors or their distance apart, is made in the city rules, a function of the pressure or potential to be carried by the wires, as it ought to be. This I understand from conversing with the parties who have prepared these excellent rules. These rules have been made not perhaps on a strictly scientific basis, but, as a means of reconciling in a fashion that at least accords with the facts of experience and those of accepted practice, so as to produce rules which will not interfere too much with what has been done in the past, and at the same time will form a good guidance for what is to come in the future. Now, while I think that several of the excellent features in these City Fire Department rules, may apply more strictly to the work that is done in and about New York City, yet I also think that a complete, comprehensive code, such as a national code ought to be, should pay some deference to the good features of those rules. There are some points there which are very carefully discussed, more especially for instance, in relation to cut-outs, whether they be electro-magnetic or panel cut-outs or ordinary porcelain base fuse cut-outs, the subject being treated in a very logical, clear manner. There is also this very question of dynamo and motor installation which Mr. Sachs referred to. I find quite a variation between the two sets of rules. In New York City, for instance we are placed in the predicament of one rule asking us to insulate a dynamo and another rule asking us to ground it, and it would evidently be a difficult matter in a case of that kind to do what both ask. I remember once being asked under the old rules, in connection with a very large building not far from where we are now, to run wires in moulding with the capping left out. The next day another inspector came, and insisted, under the same rules that we must have it on. Of course I could not do it both ways. Finally, I had to have a conference at which something like ten different inspection authorities were present, and at which it was finally decided after several sessions, to do this and also other details in a certain manner, which by the way, did not particularly follow the rules. Now, in relation to the installation of dynamos, to take that point alone, (since I have not sufficient familiarity with the rules, as I have said to go into it more deeply), it seems to me that some reference might have been made to the particular kind of dynamos—whether they be for high electrical pressure or low electrical pressure, whether they be intended for central stations or for isolated plants. I think it makes a great deal of difference. With the present direct-connected dynamos it is a physical impossibility to insulate without detriment to mechanical integrity and stability and it is also more or less, in many cases an impossibility to provide an insulated platform around them. So what is one going to do? One set of rules suggests that we had better ground them. I incline to the opinion that this set of rules may be about right, for an isolated plant and for low potentials, though the circumstances may be quite different in a central station and for high potentials. I think that in a central station, it might be desirable, especially with higher potentials, to insulate them under all circumstances, merely on account of the greater safety to human life. But where danger is not to be feared, with low pressure, I do not think it makes much difference whether the machine is insulated or not. It is certainly more convenient to have it un-insulated, and in that case the trouble or difficulty will be at the dynamo and will not spread to other places. Therefore gentlemen, I hope very much that we will take some sort of action which, while expressing our commendation and approval of the beautiful work which has been done by this committee, will not nevertheless commit us in such a manner as to compel us, either tacitly or in any other way, to approve the rules and compel us to stick to them to the disparagement of other rules that may have a greater priority of action and greater force upon us. In a municipality like New York for instance, especially after it becomes Greater New York, it may become a question as to which of the sets of rules shall have priority over the other. I myself believe that these matters should be entirely controlled by the municipality, and that all other rules should be subservient to municipal rules. It is certainly very desirable that there should be only one set of rules, and as the municipal government assumes to dictate and prescribe rules in relation to the details of buildings generally, and all details which affect public life and public safety, it seems to me that it can also be prepared and competent, or ought to be, and that it is within its legitimate province, to institute rules and prescribe regulations which apply to safety in electrical matters as well as in others. That being my view of the matter, I would certainly dislike to be placed in a position where I must disobey one in order to obey the other. I want to be placed in a position where I can obey the two.

With regard to the rules which are not exactly apposite, or which appear to be somewhat absurd or which include regulations that are not entirely adequate, I may state that those things to a great extent cure themselves. Let a rule be issued which is incompetent or which is not consistent, and it does not take long to discover flaws in it; and the "breach" soon becomes more honored than the "observance," because the observance becomes so ridiculous and so absurd that it is no longer insisted upon. Consequently I do not look for very much trouble on the score of rules which are not perfect. No one can expect perfect rules. All that I would ask is that in regard to those rules which are not consistent with other rules, (where one is placed in the position of having to defer to various authorities), that there should be no binding action whatever compelling one to obey one set in preference to any other set.

MR. HAMMER:—Mr. Chairman.—Referring to Mr. Mailloux's remarks about insulation of the machine, I would like to call attention to the two sections in the two codes so that you will note how closely they arrive at the same conclusion. The National Electrical Code says:

" Must be insulated on floors or base frames, which must be " kept filled to prevent absorption of moisture, and also kept clean " and dry. Where frame insulation is impracticable, the inspec- " tion department having jurisdiction, may, in writing permit its " omission, in which case the frame must be permanently and ef- " fectively grounded. A high potential machine which, on ac- " count of great weight or for other reasons, can not have its " frame insulated from the ground, should be surrounded with an " insulated platform. This may be made of wood, mounted on " insulating supports and so arranged that a man must always " stand upon it in order to touch any part of the machine."

Now the City Fire Department rules cover that point in this manner.

" Must each have the frame permanently connected to ground " unless surrounded by an approved insulating platform which " will be required for all generators of over 300 volts. Platform " must be of sufficient size to prevent personal contact with gen- " erators except from platform."

It seems to me they are synonymous.

MR. MAILLOUX:—I think they are far from being synonymous. The national rules have a string tied to the permission for doing it while the city rule says distinctly it is only for machines of a certain potential. It brings in the important point I made that the question whether the machine should be grounded or not depends upon the pressure of the machine which is to be installed. I think of the two rules, no one who is familiar with installation work will doubt or dispute that the city rule is much the more logical, consistent and perfect.

MR. C. M. GODDARD:—They say that faint heart never won fair lady. I suppose the fair lady we are after to-night is uniformity of rules. There does not seem to be any difference of opinion on the subject that uniformity of rules is an extremely desirable thing. We never shall get uniformity by discussing the details of the rules in a meeting like this to-night. I have been very closely connected with this matter of rules as far as the underwriters are concerned, and for the last seven years I have labored as best I could to secure uniformity of rules among the underwriters. I do not believe there are many gentlemen here, except those who have been connected with the National Conference, who realize the difficulty that we had to secure such uniformity among the underwriters. It was worse really than the effort to secure uniformity among all the different interests that are connected with electric installations. There are a great many more independent boards of underwriters, than there are national associations which have been working on these rules, and every board of underwriters had its own code of rules. Of course some of them agreed and some of them did not, and we had to get together and the majority had to win the day, the minority had to yield. There are portions of these rules that I do not agree with at all. They are not very essential points, but there are many things in the rules that I would like to see changed, and in our meetings of the delegates we discussed those points and I did my best to get them changed, but if I was outvoted that ended it until the next meeting. There are details in these rules to-day that probably we shall want to change within a year. There are undoubtedly points in the New York City Fire Department rules that are better than these; but you cannot put them into the rules at this meeting. There are a number of bodies that are connected with the getting up of these rules and you are only one of them. The time to make changes is when we have our next general conference. If there is anything wrong with these rules it is sure to come out, and we are sure to find it out and it is sure to be recognized and they will be changed. I believe that the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS to-night has an extremely important,—I was going to say duty, I will call it function, to perform. I would rather see these rules approved by this INSTITUTE than by any of the other bodies represented in the Conference, and I do not mean with any string to the approval either. I want to see Dr. Kennelly's motion go through. I want the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS to take a stand one way or the other, and either say that they will or that they will not approve the rules. I do not want them to say that they approve of uniformity. Of course we all approve of uniformity. We will never get uniformity unless we have something to start with. You have got a set of rules here which represent the best efforts of delegates who were supposed to be competent to represent the various national bodies which were collected together in the National Conference on Standard Rules. I have some personal knowledge of the amount of labor that these gentlemen put into this work. The rules were submitted and re-submitted, they were studied over and worked over. The wording of them has been worked over and studied over and they have done the best they could. They believe they present something to you to-night that is better than anything that has been presented to you before. I think these gentlemen here present believe that. They do not believe it is perfect, they do not say it is perfect, but they do believe it is a step in the right direction, and that we have got to take that step before we will ever advance a second step, and I hope that the INSTITUTE to-night will take these rules as they are, and not go into the details unless they find glaring errors and I do not believe they can find those. I do not believe that there are any glaring errors in these rules; if there were they would certainly have been discovered by some of the representatives who have been at work on them, they would have been discovered when they were presented to the National Electric Light Association. I am sure that we will get nearer to uniformity by adopting the rules which have come from the representatives of these nine national associations connected with electrical work, than we can by accepting any other one set of rules whether it be that of the New York City Fire Department, or the Phœnix Fire Office of England, or whatever they are. I believe that your delegate to the Conference presents to you here to-night a set of rules which is in advance of any other as a whole, and I believe that the gentlemen here present, if they would study these rules and were as familiar with them as I am, and I think I can say advisedly that I do not believe there is anybody that is more familiar with them; I have read the proof of these rules at least ten times during their printing, besides having seven years experience on the previous rules, working on them as Secretary of the Underwriters Association—if they were as familiar with these rules as they might be, they would find that these differences which they claim exist, could be explained away in just the same way that Mr. Hammer has explained the difference between the New York City rules and the National Code in regard to the grounding of generator frames. The Inspection Department having jurisdiction—which is it? What is it? If it is in New York City it may be the Fire Department of New York City, it does not say the Underwriters' inspection department, it says "the inspection department having *jurisdiction*." The National Code gives permission to the inspection department having jurisdiction to allow the omission of frame insulation if you find it impracticable. I think that any man would feel that it was impracticable to disobey a city ordinance. The New York City Fire Department rules say you *must* ground your generator, and the National Code says you *may*—there are reasons from the underwriters' standpoint why if a generator can be insulated from the ground we prefer it, but we realize perfectly the absolute impossibility of the direct-connected machines, the heavy machines not being grounded. It would be worse than if they were grounded, and all we say is in such cases, ground them, and ground them THOROUGHLY. I do not believe you will find so many differences in the rules as you may think on the first reading, and I do hope that whatever the INSTITUTE does to-night, the members will come out fairly and frankly and say either yes or no.

DR. CARY T. HUTCHINSON:—I think the last speaker ignores the entire difference between the position of the INSTITUTE and that of the underwriters. It is the function of the underwriters to secure the greatest possible safety in all work, so as to diminish as far as possible the fire risks and the consequent losses; that is, the interest of the body is chiefly one of dollars and cents. The INSTITUTE, however, should take a broader position, and should concern itself with the engineering features, and should not endorse any plan which involves bad engineering, even though it may seem to increase the safety of the work.

I agree with the previous speaker in saying that these rules should receive the approval of the INSTITUTE, yet I think this approval should be qualified by some form of recommendation, leading to the modification of certain rules, which I think involve unwise limitations on the engineering points, without any corresponding increase in the security of the work. To illustrate, rule 12, section *n*, provides, “For the diminution of electrolytic corrosion of underground metal work, ground return wires must be so arranged that the difference of potential between the grounded dynamo terminal and any point on the return circuit will not exceed 25 volts.”

As this rule stands, no engineer will be permitted to lay out a trolley system involving a maximum loss of more than 5% in the ground return. It seems to me obvious that this is an unwise limitation, and is entirely too sweeping in its scope.

Rule 39, Section *a*, reads, “Secondary wires must be installed “under rules for high potential systems when their immediate pri- “mary wires carry a current at a potential of over 3000 volts.” This rule refers to what are classed as extra high potential systems, that is, over 3000 volts in a primary. Under this rule when direct transformation is made from, say, 3500 volts to anything below 300 volts, the secondary wires must be run on porcelain insulators, separated at least four inches and in plain sight. This practically prohibits the use of such secondary wires in any building.

The only alternative is to make a double change from the 3500 volts, or whatever it may be, to the secondary; that is, to install two sets of transformers. This would involve a very considerable increase in cost, would sometimes require space which is not available, and would greatly increase the complication of the system.

The explanation following this rule indicates that it was framed to apply chiefly to danger from lightning striking the high pressure overhead wires. It does not seem that underground circuits were considered at all, yet it is plain, the rule would apply to high pressure underground feeders run in conduits. The rule also implies that the insulation of the transformers is the weakest part of the system ; whereas at the present day, I think that most engineers would agree with me in saying that the insulation of the transformers is the strongest part of the system.

The engineering plan excluded under this rule, is now in use in almost all of the high pressure plants in the country. For instance at Sacramento, Portland, Fresno, Pelzer, Columbia, and at other places that I do not now recall. Should this rule be adopted, all such work would be prohibited.

I have talked with several members of the Conference regarding this rule, and can find no one who remembers any discussion on it. It seems to have escaped the notice of those present.

These two rules illustrate my position in saying that the INSTITUTE should not endorse bad engineering. I have no doubt that there are other rules of similar character. I think, therefore, that Dr. Kennelly's motion should be amended, so as to provide for the re-consideration of such rules as these, while endorsing the National Electrical Code as a whole.

THE CHAIRMAN :—I see we have with us this evening Mr. A. H. Henderson, Chief Inspector of the New York Fire Department. May we hope to hear from Mr. Henderson in furtherance of the discussion?

MR. ALEX. HENDERSON :--I am not in a position to discuss these rules here to-night, gentlemen. I did not expect to be called on to take any active part in the discussion this evening. I came simply as a guest of the INSTITUTE, and for that reason I may not be able to go very thoroughly into detail. There is apparently an impression that there is a vast difference between the rules recently published by the Fire Department, and the rules published by the National Board—the National Electrical Code which we are now discussing. As I understand the matter, I do not see that there is any great difference between the two sets of rules. A great deal of care was taken in drawing up the municipal rules, to follow the principles of the National Electrical Code and to so express those principles as to make feasible rules and to make them apply to the work that is being done in New York City, realizing that no set of rules that was national could be applied locally for all classes of work. We have work going on in New York City that requires different expressions and different interpretations of rules, and we have taken the old national code and endeavored to interpret it and amend it to suit the requirements of to-day in New York City only, without any reference whatever to national work, or work in other sections of the country. I do not think that the municipal authorities have any desire to do anything but follow the principles laid down in the National Electrical Code. If there was any evidence of any such desire I should certainty be one of the first to combat it, because I think that the National Electrical Code that was first published in 1892 is one of the grandest pieces of work that was ever put into print so far as electrical installation is concerned. I think that national code covers the entire ground in a wide, broad form, but it certainly can be modified and can be amended to suit local conditions. I do not think that the framers of the code intended, in fact I am positive that they did not intend the code as printed to-day to cover the requirements of every city in the country. There are various statements that you find in it, that certain rules must be left to the decision of the local inspection board or local boards or bureaus having jurisdiction.

MR. HAMMER:—I would like to add a word to what Mr. Henderson has said. A similar condition of affairs existed in the city of Boston. Captain Brophy, who was the expert of the Commissioner of Wires there, brought up before the Code Committee of the National Conference certain points which he felt their local conditions necessitated taking cognizance of, and there was quite a lively discussion for some time upon those points which Captain Brophy brought up. Mr. Goddard was there at that meeting and he will appreciate it. And finally Captain Brophy realized that the question of recognizing one single standard code was of such tremendous importance that these local conditions need not affect the situation at all, and his association was prepared then to recognize the National Electrical Code and the suggestions governing certain local points there were put in as an appendix to cover points which, as Mr. Henderson said, are purely local conditions which they have to deal with; and it seems to me that should be done here, and I am very glad to hear Mr. Henderson express himself so strongly in favor of the recognition of the National Electrical Code, because I think that the Fire Department will also recognize the National Electrical Code and that we will have but the one single code here in New York as well as throughout the country. It is only a short time ago that we had four or five of them here. The Edison Illuminating Company had their code, and they had their own inspection. Mr. Fremont Wilson who represented an independent set of insurance interests adopted the National Electric Light Association Code and used that. The New York Board here, practically adopted the rules of the National Board of Fire Underwriters. But they introduced modifications, making quite a different code in certain respects, and then the City Fire Department came in as a new element with its set of rules, so that there were four or five different sets. Now it is self-evident that that sort of thing introduces immense complications, causes immense loss of time and money, and much inconvenience and annoyance. Everyone here must recognize that this code is not absolutely perfect, but we must stick to the main point which is the recognition of something that will represent uniformity and be the standard code; and I think that Mr. Goddard and the insurance men here will support me in stating that anyone, whether he is an electrical man or an insurance man, or represents any allied industry, who desires to bring his recommendation or criticisms, before those who will hereafter control the future editions of the National Code, will receive respectful attention, and if I am not mistaken Mr. Goddard said a little while ago "they are bound to receive recognition." I do not think there is any doubt of that. I am very glad this discussion has taken place, because the matter was taken up at our meeting at Greenacre, Maine, and as there was a comparatively small attendance there at the time, Dr. Crocker and myself and others objected to its being discussed at that meeting and requested that the matter be deferred to a special meeting here in New York City, in order that no one might feel that there was an attempt to force this thing down anyone's throat, but that it should be thoroughly discussed and that the INSTITUTE would act only after an intelligent discussion of the subject.

MR. GODDARD:—Mr. Chairman,—I would say one word in reply to what Mr. Hammer has said in relation to the meeting of the Underwriters Association. The Electrical Committee of the Underwriters Association is composed of twelve, I think, but if any of you attended our meetings you would not know there was any committee. We usually have from forty to fifty present at the meetings, and never in the five years that the association has been in existence and the Electrical Committee been meeting have we taken a vote of the *committee*. Every gentleman who is present is given the full privileges of the floor and of voting. It has not been confined to the underwriting interests, as Mr. Henderson of the New York City Fire Department and Mr. Cole of the Boston Wire Department, and Mr. Stern of Denver, and Mr. Haskins of Chicago, have been present at those meetings and taken part in the discussion and voted just the same as though they were members of the committee, and we should be glad to see every member of the INSTITUTE at our meetings, and if you will all come we will manage to find a room big enough to hold you. I do not suppose you all will come. I wish more would come. It is certain that for our December meeting, invitations will be sent in some way to all of the societies which have been represented in the National Conference to be present at the meeting of the committee and to take part in the discussion and in the voting. They will undoubtedly be accorded the full privileges of the committee, and that is the time to make changes in the rules You cannot do it here That is the time to bring up the different points in the rules. It is usually done by taking the rules up section by section. We start at the beginning, and we read the first section and ask if there are any suggestions or improvements to be made and go right through the rules one after another in that way, and we have done that year after year for the last five years, and it was the result of these amendments or changes being hitched onto the different rules that made the re-codification of the rules necessary, and that alone has been worth all the work that has been put into the whole conference. Uniformity is worth all the work that we could *ever* put into it.

But the re-codification is worth a great deal. It has brought the rules up to date so that they are intelligible and up to the present practice in electric installations. But every gentleman here may rest assured that he will be welcome at our next December meeting. We hope not to make many changes then in rules that have been issued such a short time, but any important changes that are called for, of course will be made, and the gentlemen will be welcome to discuss the rules and to vote on the changes, and there are enough members of the INSTITUTE to outvote the twelve members of the Electrical Committee of the Underwriters I am sure.

MR. S. DANA GREENE:—It seems to me that Dr. Hutchinson has indicated the proper course for the INSTITUTE to take with reference to these rules. As he says I do not think anyone will dispute with the other gentleman who has spoken as to the tremendous advantage in having one uniform set of national rules recognized by the various underwriters' associations as well as by engineers and manufacturers. But I do think that the INSTITUTE should have a proper regard for itself with respect to technical points, and that some action should be taken by it to study the rules from the engineering standpoint to see whether they have any recommendations to make for changes. I quite agree with Mr. Goddard that it is impossible to take rules which are as extensive as these, and which have taken so long to prepare as these—to take them in one night or a couple of days and be able to discuss them intelligently. But I think that the point raised by Dr. Hutchinson with reference to high potential circuits is very well taken, and that neither the engineer nor the manufacturer interested in the high potential power transmission installations of to-day is worried about the insulation of the transformer. He worries less about that than about any other part of the line, and it seems a very great hardship on a company installing the transmission line, that it should be obliged either to observe all the precautions of high potential wires on the secondary circuits or else introduce a double loss by introducing another set of transformers. I am not clear as to whether the National Conference is to be continued as a body to which suggestions and recommendations can be made for the changing of these rules, and I should be very glad to have some information on that subject. It seems to me, however, that it is the duty of the INSTITUTE, while approving these rules as they stand, so that they may be passed upon officially by the INSTITUTE, to appoint a committee of competent engineers to study these rules carefully so that they can suggest any modification which from the engineering standpoint, should be in the opinion of the INSTITUTE adopted, and if the National Conference is to be a continuing body to which suggestions of that kind can be made, I should like to make a motion, if it is in order, that a committee of that kind be appointed to study the rules and to make such recommendations at a later meeting as they see fit. I move that as an amendment, that the rules be approved, and that a committee be appointed simultaneously.

MR. HAMMER :—I suppose it is necessary in this connection to answer Mr. Greene's question about the Conference and also to explain the first pages in the special edition of the code, and the fact that it is printed as a special edition. When the National Conference met in this room it held a session of two days and then adjourned, leaving the matter of the preparation of the code in its final shape in the hands of a code committee of seven, with the President, ex-officio, a member of that committee, and they were to report back to the Conference, and a motion was made that the date of the calling together of the Conference should be left to the discretion of the President. The Code Committee represented the principal associations that are represented in the National Conference. After they had prepared the code and it had met with their unanimous approval, the question came as to the advisability of calling the Conference together as a body. If you will look over the list of names that are given there of those who attended the previous meetings of the Conference, you will see that they came from all over the United States. To have called those gentlemen together again would have necessitated a good deal of inconvenience and time, merely to receive the report of the Code Committee and practically endorse their findings, which undoubtedly would have been done. After consulting the various gentlemen who attended the meeting of the Conference it was decided that it would be unnecessary and inadvisable to call the Conference together as a body, and the code was then published by the National Board of Fire Underwriters and through its courtesy the facilities of its printer were extended to the National Conference on Standard Electrical Rules and this special edition was printed. In order that those who took part in the Conference and particularly those who contributed financially to assist its work, should know what was done with the money that was appropriated, and in order to bring to a satisfactory conclusion the work of the Conference, the special edition of the code, also includes the reports of the officers and Code Committee, together with a list of those who took part in the Conference, and it has been understood among the members of the Code Committee and others who have discussed the subject, that it was inadvisable to call the Conference together at any time in the immediate future; we felt matters could be safely left in the hands of the National Board of Fire Underwriters on condition that they would do as they said that they positively would do, throw their meetings open to anyone who has any interest in criticising and discussing and improving the National Code, and that at any time in the future, whether it be near or far, if the occasion should arise when it would seem to be advisable to call together the National Conference again, that these various associations would be again called together to take further action. Personally, as the presiding officer of the National Conference, I do not believe that that will be necessary, and it seems to me that matters should be left to stand as it has seemed best in the judgment of the gentlemen identified with the Conference to allow them to stand, and therefore I do not think that the members of the Conference expect to be called together or will be called together in the immediate future, and if this proposed committee is appointed, which I think is an admirable suggestion of Mr. Greene's,—their recommendations should be made to the National Board of Fire Underwriters.

THE CHAIRMAN:—Before having any further discussion on Mr. Greene's amendment I would like to ask if Mr. Greene's motion has been seconded.

MR. HAMMER:—I would like to second that motion, in-so-far as it relates to the appointment of the committee, if he would make that as a separate motion.

THE CHAIRMAN:—As I understand it, Mr. Greene offers an amendment to the original motion, which has been seconded by Mr. Hammer, that the code of rules as presented, be received and adopted by the INSTITUTE and that a committee be appointed from the INSTITUTE to receive suggestions as to desired modifications of the rules, that committee to report to the National Conference or the National Board of Fire Underwriters at their next meeting.

MR. GREENE:—You have not got my motion quite right, Mr. Chairman if you will excuse me. My suggestion was that this committee should be a committee of the INSTITUTE to report to the INSTITUTE as to whether it, the INSTITUTE, should recommend any changes in these rules: if so, that the changes should be made. In making that motion I asked the question which Mr. Hammer has now answered, whether the National Conference was a continuing body, and it seems to me that that was an important part of the proceedings here to-night. If the rules which have been formulated by the National Conference consisting of nine associations, of which the National Board of Fire Underwriters is one, are to be adopted, it seems to me that that organization should be continued, to consider any possible modifications, because it hardly seems proper that the National Board of Fire Underwriters, however good their intentions may be, and however competent they may be to revise these rules, should have sole say with reference to their revision, when they have been adopted and passed upon by eight other national organizations, as well as the Underwriters' Association. It does seem to me therefore that the National Conference should be kept intact as a body, and that it should be called together periodically, or whenever occasion requires, by the President of the Conference; and I move an amendment to Dr. Kennelly's motion, that the rules be approved by the INSTITUTE as a whole, and that a committee be appointed by the Council to report to the INSTITUTE at a future meeting any revisions which in their judgment are desirable, and which should be recommended to the body originating and formulating the rules.

MR. MAILLOUX:—I would like to move an amendment to Mr. Greene's motion by inserting after the word "approved;" the following sentence: "In the sense suggested in Dr. Crocker's report."

MR. GREENE:—I accept Mr. Mailloux's amendment, and I would like to say with Dr. Crocker that all that was necessary is that the INSTITUTE should approve the code as representing uniformity and co-operative action. I think that is what Mr. Mailloux had in mind.

MR. SACHS:—Mr. Chairman,—The main function of a set of rules is to set down certain principles and not to dictate the style, quality or economy of the construction adopted. It is utterly impossible to codify all the various views of those interested, in regard to each specific class and style of construction. Each particular type of construction or installation work may be governed by certain essential considerations. This code for instance, has been evolved by representative men who are thoroughly familiar with the needs of the day. One of our own most prominent members, in fact our President, has represented this INSTITUTE, and I think that he has been most thoroughly competent in the discharge of his duties. Notwithstanding this fact, when it comes to the question whether these rules agree with all the other national rules, we will find that they certainly do not. While perhaps certain lines are followed, yet there are details which may modify the basic idea in the wrong direction. The desired code must be safe, but not essentially economical, or in keeping within any specific construction ideas. As Mr. Goddard has said, these rules are not infallible. They contain elements that he himself does not in fact think are correct. But they give us to a great extent a certain basis of operation which can be handled and moulded afterwards to suit general conditions as they come up. A uniform code throughout the country can only be possible, if every interested body adopts the same basic law which may be modified to meet specific cases, but should not be changed in any one particular case. It appeared to me that some of these possible modifications might be discussed here, but probably this work can best be done by a committee as suggested.

DR. HUTCHINSON:—Mr. Greene's amendment implies the continuing existence of this National Conference, since it says: "That the Committee shall report to the body making the rules." We have just been told that the Conference is not a continuing body, and therefore, it seems that there is no body to which this committee could report.

MR. HAMMER:—I do not think the gentleman has been told that. If within a week, the gentlemen who took part in the

National Conference decide that a meeting should be called, as I am still in the Chair, I should feel it incumbent upon me to call that meeting at once, and if a report of that kind is sent to the National Conference, it would certainly come before myself as President or before Mr. Woodbury as Secretary and be submitted to those gentlemen who are associated with the National Conference, and it will then probably be sent to the National Board of Fire Underwriters—but there would be no difficulty about that, nor should there be in finding out where it could be sent.

THE CHAIRMAN:—I understand then that that National Conference or the Code Committee of it is still in existence?

MR. HAMMER:—The National Conference on Standard Electrical Rules has never been dissolved. It has as yet not been called together for that purpose.

THE CHAIRMAN:—I think that is a sufficient answer to Dr. Hutchinson.

DR. HUTCHINSON:—It seems to me that the re-assembling of the Conference is purely a matter of grace, and not a matter of right. Mr. Greene's amendment would imply the approval of the rules, coupled with the possible opportunity of modifying them when the Chairman of the Conference sees fit to call that body together again. There is no assurance that the Conference will meet again.

THE CHAIRMAN:—I understand Mr. Hammer as President of the Conference to say that he would be prepared to call a meeting at any time.

MR. HAMMER:—At any time; within a week, or a month or a year.

DR. HUTCHINSON:—Understand me, I do not oppose the approval of these rules. I intend to vote for their approval, but I wish them to be approved in such a way that the INSTITUTE will have left to it a clear and definite plan, by means of which certain obnoxious rules can be modified. I think the appointment of this committee is a cumbersome way to accomplish this object. The matter should be left in the hands of the Council. I, therefore, think Mr. Greene's amendment inadvisable.

DR. KENNELLY:—I think that I voice the general sentiment in saying that nearly all of us are in favor of adopting the report; but some of us are in doubt as to the consequences of such action. No set of rules can be perfect, and even if the members of the INSTITUTE were appointed to frame such a code of rules, there would no doubt be dissentient opinions. The approval of this code of rules by the INSTITUTE as a body does not of course mean that each individual rule receives the unqualified endorsement of the INSTITUTE. Besides, changes in rules must come in a growing science and art, such as ours, and we may reasonably hope that such changes will steadily eliminate from the rules all requirements which may prove to be imperfect engineering. I hope, therefore, that the rules, as they stand, may meet with the hearty approval of the members at the present time.

THE CHAIRMAN:—We will now proceed to put the original motion of Dr. Kennelly's as amended by Mr. Greene and re-amended in part by Mr. Mailloux. Will you kindly read that motion.

The stenographer read the amended motion as follows:

> "That the report which is here presented be adopted by the INSTITUTE, be spread upon the minutes, and that the National Electrical Code, as it is here presented to us in pamphlet form, be printed in the TRANSACTIONS; that the rules be approved by the INSTITUTE as a whole, in the sense suggested in Dr. Crocker's report, and that a Committee be appointed by the Council to report to the INSTITUTE at a future meeting any revisions which in their judgment are desirable and which should be recommended to the body originating and formulating the rules."

The amended motion as read was then adopted.

MR. GODDARD:—I would like to say just one word in correction of what Mr. Hammer has said in speaking of the National Board of Fire Underwriters. He should have spoken of the Underwriters' National Electric Association, as it is their Electrical Committee that has charge of the rules for the National Board, and it might perhaps interest the members here to note that three members, Messrs. Merrill, Fitz Gerald and French, of the Code Committee of the National Conference, are members also of our Electrical Committee, so that your Code Committee always has a pretty good representation there, and if we attempt to do anything that is very, very bad, I think Mr. Hammer, as President of the Conference, would hear of it.

MR. HAMMER:—Mr. Chairman, before we adjourn, I would just like to say one word—I intended to say it before, and that is to congratulate the INSTITUTE on its appointment of Dr. Crocker as Chairman of the Code Committee, as no one whether connected with the National Conference or outside of it can appreciate his disinterested work and his energy and ability more than I, and in going to the various meetings, held in New York, Boston and elsewhere, and holding conferences with him on many occasions, I have been in a position to know that Dr. Crocker has given an immense amount of his time, and sacrificed his personal interests, and even his own health to the worries and anxieties of this code, and it has been a very difficult piece of work, and possibly you gentlemen who see it printed in this shape do not realize all this. A great deal of that burden has fallen on the Chairman of the Code Committee, and I feel that it is no more than just, to say this at this time in approval and endorsement of the earnest and disinterested efforts of Dr. Crocker in this direction.

THE CHAIRMAN:—Gentlemen, after this rather lengthy discussion I think we all of us heartily appreciate the efforts that have been made by the INSTITUTE's representative, and I should be very glad to entertain a motion that the INSTITUTE pass a vote of thanks to Dr. Crocker for his work in this direction.

[Mr. Mailloux rose.]

MR. GODDARD:—I am going to get ahead of Mr. Mailloux on that, because I stand here in a sort of dual capacity as the representative of the underwriters as well as a member of this INSTITUTE, and as their representative I feel that I would like to move that the INSTITUTE extend a vote of thanks to your delegate. We would like to do it ourselves. We have found him always ready to meet with us and talk with us, a gentleman and a scholar in every respect, and I move you, sir, that the INSTITUTE do extend to Dr. Crocker, the delegate to the National Conference from this INSTITUTE, a hearty vote of thanks for the labors which he has bestowed on that work in preparing this "National Electrical Code."

MR. MAILLOUX:—Mr. Chairman, I would like the privilege of seconding that motion, because I want to have Dr. Crocker feel that I appreciate to the full limit this work, even though I claim the privilege of having opinions of my own which may differ somewhat from his. It is no compliment to say of Dr. Crocker that he has done this particular thing well, because he does well everything that he does,—as well as he can, earnestly and truly. He is known to all of us as a hard worker and a man who is terribly in earnest—perhaps too much so—about everything he does, a man without fear or favor, and who tries to do his "dead level" best, every time. In this case the gratifying reports which we hear from the people that have been associated with him in this work are merely a corroboration of the observations we have made ourselves in relation to his work, and I want to testify to my deep sense of appreciation of the earnestness and thoroughness he has manifested in this particular work. I can understand the difficulties Dr. Crocker has had to contend with in working over these rules. I have been troubled by indigestion and loss of sleep many times from underwriters' rules and I have to do with them possibly as much as any member of the INSTITUTE. My work is of a character that brings me into intimate contact with them. Consequently, I can appreciate any effort that is made to improve them and any good work that is done in behalf of better rules. So that I think I have certainly had good opportunities to see the good work he has done, and knowing the personal character of Dr. Crocker so well, his earnestness and devotion and zeal in anything that he undertakes, I feel sure that no comment could be too eulogistic or too full of praise for the work he has done at this time. I may not, at present, be disposed to accept all his conclusions, but I certainly commend his efforts, admire his application, and applaud his ability and energy.

THE CHAIRMAN:—Gentlemen, you have heard the motion, which it gives me particular pleasure to put, that the thanks of the INSTITUTE be extended to Dr. Crocker for his able and excellent work as representing the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS on the Code Committee. Those in favor please say aye.

The motion was carried unanimously.

THE CHAIRMAN:—Before asking for a motion to adjourn, I hope Dr. Crocker will take the Chair and put that motion himself and favor us with any remarks, as we have not heard from him.

DR. CROCKER:—(In the Chair). Gentlemen, I am deeply grateful to you for your very hearty expression of thanks to me. I must confess, however, that it is somewhat tinged by a feeling that the action taken by the INSTITUTE is not what I should have liked to see done. I am sorry to have to make that statement, but I feel called upon to do so, because in my opinion the matter deserved better treatment. While in my own report I said that no binding adoption was called for, I think a much more clean-cut approval could have been made. Even now I do not know whether the Code is to be printed in the TRANSACTIONS.

MR. HAMMER:—Certainly.

THE PRESIDENT:—If not, I should certainly suggest a motion that it should be, because the discussion will appear in the TRANSACTIONS and I think the Code will stand comparison with the discussion.

[Adjourned].

NATIONAL CONFERENCE ON STANDARD ELECTRICAL RULES.
12 WEST 31ST STREET.

New York, Dec. 10th, 1897.

RALPH W. POPE, ESQ., SEC'Y. AM. INST. OF ELEC. ENGINEERS,
26 Cortlandt St., New York.

DEAR SIR:—In printing the report of the meeting at which the "National Electrical Code" was discussed and approved by the Institute, I trust that cognizance will be taken of the fact that in addition to the six Associations whose names were given as having already approved of the Code; that approval was subsequently given by the three (3) remaining organizations, *i. e.*, the American Institute of Architects, the American Street Railway Association, and the American Society of Mechanical Engineers

Respectfully submitted,
WILLIAM J. HAMMER,
President of National Conference
on Standard Electrical Rules.

Discussion in Chicago.

The meeting of the Western members of the American Institute of Electrical Engineers was called to order in the Lecture Room of the Armour Institute of Technology, Chicago, Ill., on September 29th, 1897. at 8 o'clock, by Vice-President Stine. The discussion was opened with Mr. A. S. Hibbard in the Chair.

The Chairman, (Mr. Hibbard):—Gentlemen, we have for the consideration of our meeting to-night rather an important matter for us as members, and for all of us who are interested in wiring, or the operating and installing of wires. We are fortunate in finding in these rules which have been furnished us, the result of a number of meetings, which have been held during the past year, and compiled by the delegates from our own association, from the American Institute of Architects, the American Society of Mechanical Engineers, the American Street Railway Association, and representatives of the insurance and municipal interests. There are a great many rules given, but, I think in reading them we will find that they are the result of former rules, modifications in many instances, and showing improvements in many others. It will not be possible, of course, in the limited time of this discussion, to take them up, one by one, or page by page. In a general way, however, and in the interests of the various members, it will be possible to consider them.

We are fortunate in having at our meeting to-night one of the members of the body by which these rules were formulated,—Mr. W. H. Merrill, of the Chicago Underwriter's Association. I think, after we have heard from some of our members in a general way on the subject, it will give us all a great deal of pleasure to hear from him. It is suggested that the discussion of the subject in general and as much in detail as our various members may wish, will be begun by members of the Institute. It is interesting to know that the members of the Institute in New York are taking up the same matter to-night, and there is no reason why the general work we do should not follow the line of what takes place there this evening. I would like Mr. Pierce to begin the discussion.

Mr. R. H. Pierce:—I did not expect to be called upon to start up the discussion, for I have not taken any time to make special preparation for it, and had no warning. I am a little ashamed to acknowledge that I have not followed up the recent discussions and papers that have been written on this subject. There has been so much written on this question, and everyone has had so much to say about it, that I really got tired of trying to keep posted on all the views, and just whose ideas are embodied in the recent changes, I am sure I don't know.

I think I am hardly the one to start the discussion to-night, for the reason that the only way to get what is really a good discussion

—that is, the *pros* and *cons* of a subject of this kind, is to start up a strong spirit of antagonism and oppose the rules. That would awaken the champions of the cause, and would bring out a discussion. I have in the past put myself in such a position that I could not consistently play the role of an opposer. I hope there is some one here who has some interest, from a commercial point of view,—some one who will take exception to parts of these rules, because we have a good champion in Mr. Merrill to bring out all there is to say on the *other* side. The only thing that I have heard againt the rules lately, was said by a manufacturer of wire. He said he sold but very little of his highest grade of wire, because the rules specify a long list of wires, and a customer who wants to wire a building is told that he must use one of the wires designated by the underwriters. Instead of stating a certain make, the customer simply says that it must be a wire specified by the underwriters. This gentleman told me that as a result, the cheaper grades of wire have become still cheaper; that they make them as cheap as they can be made and put on the market, and on account of this demand for an inferior product, he sells more inferior than high grade wire. The moral to all this is that we should not look upon the Electrical Code as being a complete *specification*. I think that we are all very glad, those of us who have occasion to draw up specifications, to have something which governs as well as this Code does, all branches of the work in a general way. It is only a few years ago, when, in writing up specifications, nineteen-twentieths of the specifications consisted in a description of methods and devices necessary to secure safety, and it was simply covering in a poor way and in many words what is covered in a very good way, and in a few words in this Code. Now, instead of writing fifteen or twenty pages of details, we simply say: "Such and such things must be in accordance with the latest edition of the National Code."

But the architect and the man who wants to put in a plant or installation, without any specifications, simply states the capacity of his plant and machinery, how many lights he wants, and then states that the work must be done according to the National Code, and thinks he has done the whole thing. I think if I were to make any criticism at all, it would be on the way the Code is *used*; it is used often for something for which it was not designed;—that is, it was not intended to take the place of specifications. The engineer and the architect are supposed to take care of them. If I understand the object of the Code it is to secure safety to those who handle and use the electrical energy, and there is little that can be added in the specifications now in the way of securing safety excepting in the selection of such materials and methods as are particularly adapted to the special conditions. If engineering work could be classified so that we would have a certain number of cases and designate them, so we could find Case No. 1 and use such and such material, Case No. 2, use so and so, it would be different. But it has been my experience that every piece of work, where you try to get the best results for the least money, is, to a certain extent, a *special* case. Whereas the Code, of course, treats every kind of a case in a general way, of course it does not and cannot particularize in these special cases. This may be a small point to dwell upon, but I have in the past spoken so enthusiastically of the Code and acted as its champion among central station men and others whom its requirements have hit in the pocket, that I have not left very much ground on which to stand to criticise it. I hope that there may be some one here who has given the matter more thought than I have, and who will start a discussion which will bring out the views of both the friends and the opponents of the code.

THE CHAIRMAN:—I think that the remarks of Mr. Pierce have brought out a tangible point or feature which underlies all the rules, and as he has brought up one point of criticism, possibly Mr. Merrill will help us out, as these points are brought up. If he can answer that particular point now and some other point later on, as it shall be brought up, it will save his time, and enable us to take it up while it is fresh in our minds.

MR. W. H. MERRILL:—I know that Mr. Pierce, as the author of a work on the National Electrical Code, and also as the author of a paper on this topic read before the Northwestern Electrical Association, can hardly be expected to start out and criticise the rules. He overlooks the fact, however, that the list of wires is not published in this book. The rules, as he states, were formulated solely along the lines of promoting safety, and were not intended to cover specifications that an engineer should be called on to supply. The rules governing safety do not take into consideration whether a man puts in a machine that is twice too large for his plant, or not. Every installation needs an engineer in addition to an inspection under this Code. The engineer may do the inspector's work, but the inspector cannot do the engineer's

MR. A. V. ABBOTT:—The tendency of civilization is, it seems to me in every direction towards specialization. In savagery each man supplies his own wants and furnishes himself by his own labor, with all that he needs. With the progress of civilization, however, the time soon arrives when it is impossible for each individual to supply his increased diversity of wants, and humanity splits into divisions, each one selecting some different line, or avocation, and becoming therein an expert, while succeeding generations elevate the particular branch to a higher point than the majority of his competitors. Thus, as a result we presently learn to depend largely upon the labors and efforts of others for the supply of our multitudinous desires. In no direction is this tendency more marked than with engineering. It is barely 20 years ago since civil engineers were the only members of the profession, whereas now the art has been sub-divided, and electrical engineers, mechanical engineers and sanitary engineers share the honors with the older members. Such a subdivision is particularly necessary in engineering, for during the last few years, the scope of the profession has broadened to such an extent as to make it impracticable for anyone to become even a partial expert along all lines. This is markedly the case in dealing with electricity, for in electrical lines we are handling a form of energy that is comparatively new, one in which experience is exceedingly limited. It is a particularly subtle and elusive form of energy, and while on the one hand these very qualities enable it to be handled and made subservient to the welfare of mankind in ways impracticable with other forms of energy, it is on the other hand correspondingly dangerous and difficult to control, and liable when treated in an ignorant and unskilful manner to do a correspondingly greater amount of injury. However, in this respect electricity is not exceptional, for there is scarcely anything employed in the service of mankind, which, if improperly used or ignorantly treated, is not prone to become a source of danger. This is markedly the case in medicine, with steam, with explosives, and with machinery of all kinds. The fact that electricity has been so recently applied and that its introduction has become so rapidly widespread, makes it particularly necessary that it should be skilfully handled under proper rules and restrictions, and for this reason I think we should be gratefnl at the present time for the care and pains which have been taken in forming a code, giving such rules and instructions as the best present experience indicates advisable in dealing with this form of energy. At best there is so much that is unknown about electrical installations that they are certain to become sources of extreme hazard if they are not introduced in the best and most skilful manner, and it is impossible to expect that the mass, even of artisans, will understand completely a subject that fifteen years ago had but two practical applications. Men in active life find it difficult to keep pace with ordinary events, to say nothing of thoroughly acquainting themselves with the strides which have been taken by electricity. Now the best experts in the country have taken the matter in hand and have here formulated a Code so simple and yet comprehensive that ordinary mechanics can, by strictly following the same, build safe electrical installations. The Code, perhaps, has still another vocation, for we are aware that in all classes of builders and constructors there is a tendency not only to do ignorant work, but that which is unscrupulous as well. We are acquainted with the existence of builders who take contracts at such prices that it is impossible for them to fulfil them without either loss of money or the evasion of the proper methods of construction, and unless around such unscrupulous constructors a hedge is built so tightly and so carefully as to prevent them from thus unscrupulously introducing defective work, the public is bound to suffer; but if, from time to time, such a set of rules and regulations as we are now considering be formulated, and if it be adopted with so strong and vigorous public spirit as to render it impracticable for unscrupulous as well as ignorant artisans to evade the same, it will be possible to obtain a quality of work and grade of materials which shall, on the whole, be best suited for the purpose, and will in the long run greatly conduce to public safety and convenience, and by relieving the public mind of the fear of danger from electrical installations, will operate as a most powerful stimulant to the further expansion of electrical industries.

I am, therefore, of the opinion that while perhaps a canvass of the Code at present, and, it may be, a revision of the same from time to time in the future, as experience shall indicate modifications to be desirable is advantageous, the important duty lying before each and everyone of us, is to take this Code up in our daily practice and by all the weight and influence in our power to see that its spirit and intention are carried out as completely as possible.

MR. S. G. McMEEN:—Is it expected that this meeting of the eastern and western members of the INSTITUTE, be the time and season when the stamp of approval will be placed upon the Code if at all, or will it be voted upon to-night?

THE CHAIRMAN:—(MR. HIBBARD). It is my understanding, that if the Code, as it stands, meets with the approval of the meeting here and in New York to-night, it will be in order to recommend its adoption by the Council of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS. If it is the sense of the meeting that it is a good thing, such a recommendation will be made to the Council. Our President, Dr. Crocker, who was a delegate to the meetings which resulted in this Code and rules, made a report to the INSTITUTE which will be read shortly. He endorses the Code and gives his reasons very briefly and well, and he undoubtedly is an attendant at the meeting in New York to-night. In his absence, we have his report, which we will hear after we have had a little more discussion, either on the general or the more specific matters relating to the Code. I do not understand that it is expected, on recommendation of a Code like this, that we obligate ourselves to never vary from the Code, any more than that we never vary from the Golden Rule, and several other things of that kind, but it is intended as showing what we would recommend and desire to bring about in our own work.

Without bringing shop matters into the discussion too much, it would be interesting, I am sure, to hear from some of the railroad people present. We would like to know how a set of rules, such as we have here, appeals to a trolley man as applied to a trolley road, and whether he feels that his plant is improved and benefited by them, and whether they are reasonable and right. I wish also that we might have an expression from a power man, one representing power plants of some kind. There has been, perhaps, a feeling that the trolley road was essentially a new thing, and while it has been improving tremendously in detail during the past five years, it has been extending so fast many of us have felt that its management frequently either had not the time to look into details and keep off its neighbor's toes, or, perhaps, did not want to, and failed to recognize reasonable rules designed to curb and govern them. Other people, I am sure, feel that such regulation is beneficial. Whether the trolley road representatives feel that way or not they can say better for themselves.

MR. R. E. RICHARDSON:—I do not know as I can say much on that subject, although I have given considerable thought and attention to it in connection with insurance risks, etc. I believe we will all agree that the best thing that has been done in the way of insurance rules in regard to trolley wires, was the making of the rule which absolutely prohibits the carrying of a street railway circuit into buildings, and using this current for motors or lighting, which necessitated a ground in the building. It is to my mind the very best thing in an individual rule that the electrical underwriters' fraternity ever made in taking the ground circuits of a high pressure current out of, or preventing them from going into buildings.

There is one thing which crosses my mind not in relation to trolley work or railway work, but a point which it seems to me the Code has not exactly reached as yet. I may be speaking from ignorance, however, as I have not carefully read through the last Code. This is the question of line appliances in the way of safety devices, sockets, etc., for the present fashionable 220-volt work. I had occasion lately to examine a number of 220-volt lighting plants and found they were using exactly the same cutouts, same sockets, fixtures, etc. throughout that are designed for 110-volt work. While there are now 220-volt switches on the market, I do not think there has been anything done in the way of manufacturing sockets, fuses, etc., especially for this voltage. In one of the plants examined, I asked the engineer what he was using for sockets, cutouts, etc. He replied he was using the same as for 110-volt work, and in answer to my question if he did not have a great deal of trouble, he said: "Oh no; once in a while they burn out." A few moments later, I noticed a switch which was nicely cooked and asked him if that was not one of them. He replied, "yes." Going farther, I found numerous cases of the same sort. It seems to me that the 220-volts for lighting is at present the prevailing fashion, a great many plants of this voltage being put in, and I do not think that the supply manufacturers are prepared for it. For instance, take an ordinary socket which can be bought for one-half or one-third of what ought to be paid for a good article. These sockets are not suitable for a 220-volt break, as with this pressure an arc has little trouble in being formed in the socket. It is the same way with many of our fuse blocks.

I do not suppose for a moment that this subject has been lost sight of by the underwriters, but perhaps it is something that they have not yet had time to get into the rules. My own experience in examining a number of installations with this pressure is, that there is a great deal of trouble and a great many burnouts in the fixtures and in places where they would not have occurred, I am sure, if the ordinary 110-volt or low voltage current was in use. I will be pleased if Mr. Merrill will advise us as to what has been done in this regard in the way of having the manufacturer supply a line of material especially designed to accomodate 220-volt circuits.

MR. MERRILL:—I agree entirely with Mr. Richardson that the fittings at present on the market, with but very few exceptions, are unsuitable for use at 220 volts; I would go further and say that many of them are unsuitable for use at 110 volts. As far as the Code is concerned, however, I think the matter is fully covered. All of the rules relating to switches, cut-outs and similar appliances specify, first, that the manufacturer's name or trade-mark should be stamped on the goods where it can be plainly seen; second, that all of these fittings must operate successfully at 25 per cent. excess voltage and 50 per cent. overload in amperes under the most severe conditions they are liable to meet with in practice. These are the general provisions for all fittings. Besides these, you will find detailed specifications for the construction of many common appliances. Their use at 220 volts, 440 volts, 500 volts, and all voltages, is covered in these specifications. In that respect, this edition of the Code is far in advance of the '96 edition.

MR. PIERCE:—I believe that all of us ought to say exactly what we think about this Code, especially those of us who are engaged in engineering work, and I believe we would all say that the Code fulfils the purpose for which it is intended so well that it does not seem fair to criticise it. But I think, inasmuch as the Code is a matter of evolution, that if we have any one with us who considers the Code imperfect, or who has anything to suggest as to how it could be improved, we would all gain something by hearing it. I notice a gentleman here who represents a branch of the art which as yet has not been represented in our meeting here to-night, and while I do not wish to intimate that he is not an engineer, at the same time he is interested more especially in the supply business, and the changes in the Code may have helped him or may have created some trouble for him, and perhaps he will give us some insight into the matter. The gentleman I refer to is Mr. Burton.

MR. C. G. BURTON:—It has occurred to me in looking over the list of authors who are responsible for the revised rules, or as it is termed, the National Electrical Code, that the electrical associations, underwriters' associations, architects, and various other people are represented, but there is one man who is obliged to stand the brunt of all these changes, and who I do not find represented here, and he is the much maligned supply man. It is an easy matter to formulate a set of rules and say: "We will allow such and such an article." On the strength of this statement, and practically a guarantee, the supply man, who is on the alert for money-making products, lays in a nice stock in anticipation of a profitable venture, but is soon notified that the use of this particular article is prohibited and to make it still more emphatic, photographs and descriptions of the articles are widely distributed. Now where does the supply man come in?

I was very much taken with the remark made a few moments ago in which our friend advocated the idea of compelling the manufacturer to get out a better quality of apparatus. In '84 I traveled about the country trying to sell electrical apparatus and among other things a very poor grade of socket for which I endeavored to secure 85 cents. At one time I took an order for quite a quantity at 80 cents and the firm very promptly turned me down. I presume it cost them as much as 15 or 20 cents to manufacture. I can now sell a better socket and make a fair profit at 8 cents. Now this idea of compelling the manufacturer to make better apparatus is not correct. You commence at the wrong end of it. What should be done is to compel the consumer to use a better grade of material, and the manufacturer and the supply man would be only too glad to sell him a better class of material. Under present conditions a dealer will put in a large stock of sockets, for instance, which cost him a certain figure. He possibly soon ascertains that his competitors are selling sockets at a much lower price than he can afford. His only recourse is to compel the manufacturer to make a cheaper socket which enables him to meet competition. As long as the consumer will purchase and use a cheap, low grade of material, just so long will the manufacturer and the supply man handle material of that character, but in all this the supply man is the one who is blamed because he sells such poor material, whereas the real reason exists in the fact that the underwriters and others in authority do not compel the consumer to use a better grade.

With reference to the matter of wire, I notice for the first time that the revised National Code omits a long list of wires that it formerly contained. I presume that this was due to the efforts of our underwriting friends, and also to the overwhelming sense of injustice that they must have felt in putting their stamp of approval so indiscriminately upon anything and everything that bears resemblance to wire. The house with which I am connected sells a good wire; has been selling it for 8 to 10 years. Our friends, the publishers of newspapers, have been able to declare dividends on the basis of money expended in advertising and pushing this particular product. We still sell that wire at fair prices and at a fair profit. Under present conditions, however, the customer asks for quotations on wire, which we readily make. If there are unsatisfactory and he wants lower quotations, we quote him on another wire that we can purchase in the open market and which we can sell him at about two-thirds the cost of our regular and standard wire. He inquires if this cheap wire is approved by the underwriters and we can but answer that it certainly is, and we are further willing to guarantee that it does not contain over 60 and 10 per cent. of mud. The fact is that we can make more money selling the cheap wire than we can the high grade of wire which is simply due to formerly indiscriminate endorsement by underwriters' associations. Under these conditions it is but natural that the consumer should use the cheap wire where he has no interest at stake subsequent to its installation, and it is this condition of affairs that has led to a great deal of this cheap quality of construction, against which there seems to be so much objection. It is to the interest of the supply man to be enabled to sell a better quality of material of all kinds. The supply man acts as a go-between. We do not manufacture or originate material; we handle material which has been originated and manufactured by some one else, which we offer to the consumer. We would much prefer to sell a good article at 15 cents than two poor articles at 7½ cents each. When we sell staple and satisfactory goods to a customer we get his good will and the assurance of his future patronage, but if we sell him a poor affair the danger exists that it will influence him against us, so betwixt the disposition of underwriting concerns to call for a high standard, and the disposition of the consumer to purchase a cheap article, the supply man is kept continually in hot water, and is practically blamed for all the poor material. Surely we are a much maligned fraternity.

MR. RICHARDSON:—In answer to the gentleman who has just spoken, I would say that I was once connected with a large electrical supply house and think the facts in the case are these: That the supply man has a disease, but does not go to the right doctor for a cure. He does not want to go back to the manufacturer for redress, but should work in harmony with the underwriters, and just as soon as he, the supply man, will refuse to buy or sell an article, which is not first class, (and he admits it is poor policy to sell an article of inferior quality), he will then have no further trouble with his sockets, etc., no bargain counter referred to, and the customers who have bought his goods will come back to him for more of the same kind instead of being dissatisfied and going elsewhere. It seems to me the supply man has as much opportunity to help out in bringing up the standard of electrical material and appliances as the underwriters themselves.

If the supply man, as above stated, will not buy or sell cheap goods, it naturally follows that the other fellow, the construction man, cannot get and use inferior material. It does not seem to me that the keeping of seven or eight grades of a material, ranging from poor or worthless up to good quality in order to catch all classes of trade, is in harmony with the Code or the spirit in which it was written.

As previously stated, I was once connected with a very large supply house and can state from experience that the money made by that house and the reputation they gained was not made or gained by the sale of cheap goods. Where good goods are sold, they are sold to stay sold, and where poor goods are sold, they usually come back, the customer staying away. I can well remember when the sockets referred to sold for 85 cents, and it may be that a better socket than these were can now be sold for 7 cents, but I doubt it. A good socket, I do not think it necessary to tell this audience, cannot be built for 7 cents and it is just these little things that tell in an installation. An immense amount of time, energy and money is spent to bring up the standard of a piece of machinery, as, for instance, a dynamo, to get a high field, commutator and armature insulation, and then some paltry little cheap 5 cent device is connected up to the system that destroys the entire insulation of the installation. It does not seem to me that the supply man is such a terribly maligned individual, and if he has an ailment, the cure rests largely with himself.

The Chairman:—I would like to bring out the fact, that the rules we are looking over are not solely underwriters' rules. They have been made by the representatives of the national institutes of architects, electrical engineers, mechanical engineers, street railway and electrical lighting people, as well as by the underwriters. I don't think the underwriters even had a majority in the meetings. I think that if the representatives of the architects, railroads and electric lighting associations wanted to, they could have out-voted the underwriters, which they do not seem to have done. I have no doubt if there was an association of the people who make the goods, they would have joined in the same line. We have no set of rules for the supply men or for the manufacturers. It would interest us to hear something on the broad matter of the rules themselves, from the gentleman who was one of the board which made them up. I will ask for some final remarks from Mr. Merrill.

Mr. Merrill:—The printed history of the rules tells the tale from start to finish, and this Code is its last chapter. This history you may read in the little books which I have sent here, and I think probably it will prove more interesting to you in the form in which it is there presented than it would recited by me. The Code itself is not a fire underwriters' code any more than it is a life underwriters' code. The life insurance people might be just as much interested in this Code as the fire insurance companies. The Chicago Fire Department and other city departments have adopted it. It is of just as much interest to architects, electric lighting men, central station men, supply houses and electrical contractors as it is to us. The remedy for existing evils does not lie wholly with the fire insurance man. He is a pretty charitable sort of person, spending something like $150,000 a year in the vain endeavor to educate the people up to good construction, and it is unreasonable to expect him in all cases to prevent poor construction. The matter is one of general interest, and it should always be one of general education. I would be very glad if it could be taught in the public schools. Some day, perhaps, it will be. It seems to me that an institution of such a national character as yours, and one having such great potency in the matter of the standard it adopts, should consider it within your province to further this work, to give the stamp of your approval to a set of rules which has been very largely compiled by your own delegate, and in this way help along the general cause, in which we are all very much interested, I am sure.

PROF. W. M. STINE:—I have in my hands a report which is being presented in New York this evening by Dr. Crocker. He is a member of this National Conference.

[Prof. Stine read the report, see page 514.]

MR. MERRILL:—The Conference has been invited to co-operate with the Underwriters' National Electrical Association at its meetings, and consider any revision, extension, or amendment to the Code. It is not expected that it will be necessary to make any changes in this general wording for, we hope, at least two years to come, but we propose to meet again in December to talk over all the suggestions of improvements which we might receive in the meantime from any source, and if there is nothing to be revised at that time, we propose to let it stand as at present. The future work will be in the hands of these various interests, and in the event of changes of any consequence being made, it will be the duty of your delegates to report to you for further action.

MR. A. V. ABBOTT:—I would like to ask how this Code compares with similar documents in England.

MR. MERRILL:—It is altogether different. British practice, of course, differs from American practice; and while I am not very familiar with the construction work going on there, I should judge the code of rules recently adopted by one association in England, compared with this Code, could be called crude. That code has been refused by a number of fire offices there, each preferring to retain former methods. They are in the same danger there that we have been in here for several years, not only in their organization as to a code, but, beyond that, each fire office has a code of its own, which makes it very much more embarrassing than to have a code agreed upon by even all of the insurance companies. It may be that practice in England is carried on so conscientiously that such rigorous handling of rules and their enforcement is not necessary. I can see no other explanation for their being apparently so far behind the times in the way of rule-making.

MR. ABBOTT:—The code of rules that I had reference to has been received within the past month. I noticed that the carrying capacities were somewhat larger than ours.

PROF. STINE:—I would like to read the following resolution:

Whereas, The rules and requirements for the installation of wiring and apparatus for electric light, heat and power, known as the "National Electrical Code," are the result of the united efforts of the various electrical insurance, architectural and allied interests represented in the National Conference on Standard Electrical Rules, composed of delegates from the

American Institute of Architects,
American Institute of Electrical Engineers,
American Society of Mechanical Engineers,
American Street Railway Association,
Factory Mutual Fire Insurance Companies,
National Association of Fire Engineers,
National Board of Fire Underwriters,
National Electric Light Association, and
Underwriters' National Electric Association, and

Whereas, This Code is shown to be the best at present available for use from the fact that it has been adopted by the various municipal and insurance inspection departments of the country, as well as by the National Electric Light Association and the National Board of Fire Underwriters and other bodies, and

Whereas, Representatives of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, headed by the present President of the INSTITUTE, were important factors in its compilation;

Therefore be it resolved, That the "National Electrical Code" be and hereby is endorsed for general use as a standard set of specifications governing the safety of electrical equipments, and

Be it further resolved, That this Code be recommended to the Board of Management for adoption as the standard of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Mr. Abbott moved, and the motion was seconded, that the above preamble and resolutions be adopted. The motion was carried, and the above unanimously adopted, whereupon the meeting adjourned.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, October 27th, 1897.

The 118th meeting of the American Institute of Electrical Engineers, was held at 12 West 31st Street, this date and was called to order by President Crocker at 8.20 p. m.

The Secretary :—At the meeting of the Executive Committee this afternoon the following Associate Members were elected :

Name.	Address.	Endorsed by
Balsley, Abe	Chief Electrician, Terre Haute Electric Railway Co., No. 514 6½ Street, Terre Haute, Ind.	R. B. Harrison. Edw. G. Waters. Edw. P. Decker.
Balcome, Herbert A.	With The Eddy Elec. Mfg. Co., Windsor, Conn.	W. R. C. Corson. H. E. Heath. H. S. Rodgers.
Child, Chas. T.	Editor, *The Electrical World*, 253 Broadway, New York.	J. Stanford Brown. Louis Bell. A. E. Kennelly.
Goltz, William	Hathaway Building, Milwaukee, Wis.	F. B. Badt. Chas. D. Shain. B. J. Arnold.
Jones, M. E.	Contractor, and Student in Senior Class, Cornell University. Ithaca, N. Y.	Harris J, Ryan, S.B. Fortenbaugh. Fred'k Bedell.
Le Clear, Gifford,	Electrical and Mechanical Engineer, Partner Densmore & Le Clear, 7 Exchange Place, Boston; residence, Cambridge, Mass.	C. A. Adams. E. H. Hall. H. B. Shaw.
Thompson, Silvanus P.	Morland, Chislett Road, West Hampstead, London, N. W., England.	Chas. P. Steinmetz. Ernst J. Berg. Eskil Berg.
Williams, Geo. Henry	District Supt. The Edison & Swan United Electric Co., Ltd., 134 Royal Avenue ; residence, Culmore, Glenburn Park, Belfast, Ireland.	H. L. R. Emmet. A. G. Inrig. Ralph W. Pope.

WOTTON, JAMES A.	Electrician, Southern Bell Telephone & Telegraph Co., P. O. Box 218, Atlanta, Ga.	F. A. Pickernell. A. N. Mansfield. D. I. Carson.

Total 9.

The following Associate Members were transferred to full membership.

SAMPSON, F. D.	Manager, Charlotte Electric Light and Power Co., Charlotte, N. C.
DAVIDSON, A.	Cable Engineer and Electrician, Central and South American Telegraph Co., Lima, Peru.
DECKER, EDWARD P.	Electrical Engineer, New York Telephone Co., 18 Cortlandt St., New York,

Total 3.

THE PRESIDENT:—As there is no formal business to attend to we will proceed immediately to the subject of the evening, and I take great pleasure in presenting Mr. Richard Lamb, who will read a paper on a novel and very interesting branch of electrical engineering, "The Development of Electric Cableways." Mr. Lamb will please present this paper, and as the paper is illustrated by lantern slides it will be necessary to darken the room, and Mr. Lamb will refer to them in the course of his paper.

A paper presented at the 118th Meeting of the American Institute of Electrical Engineers, New York, Oct. 27th, 1897. President Crocker in the Chair.

THE DEVELOPMENT OF ELECTRIC CABLEWAYS.

BY RICHARD LAMB.

Large expenditures of thought and money have been made to devise means of transportation that can disregard the insurmountable difficulties of some surface roads, such as excessive grades, too much bridging, or too great a cost for roadway. The natural suggestion has been to make the roadway through the air, and air-ships, flying machines and suspended cableways have been sought for to solve the problem.

Macaulay wrote, "Of all inventions, the alphabet and printing press excepted, those inventions which abridge distance have done most for civilization."

The most baffling problems we have before us to-day are those of abridging distances. With all the expenditure of life and money that has been put into the endeavor, man has not as yet even been able to traverse this orb of the universe upon which we are living, and with untold riches as the goal, thousands stop within a few hundred miles of the Klondike, at the first short pass, to await a less hazardous season to risk the journey.

There are millions of feet of valuable timber in swamps standing within rifle-shot distance of convenient points of navigation that have been practically unobtainable. The miry soil makes regular roadbeds too expensive, and it has been as impossible to get the teams into the swamps as to get the logs out. It was to solve this particular problem of abridging distances that the electric cableway was built.

I first built a cableway, having portable iron bracket supports to attach to the trees, and an endless cable supported by sheaves upon the brackets. The cable was passed around a sheave which was driven by a steam engine at one end of the line. This cableway worked well, and could haul logs for a distance of half a mile, which is farther than by any other method previously tried. I found that steam cableways were limited to straight lines, and as trees do not always grow in long straight lines, I devised a means by which the car would replace the traction-cable in its sheave if it was dislodged in passing a bracket on account of the cable line not being straight. But this did not obviate the difficulty of having to select the route with reference to a straight line.

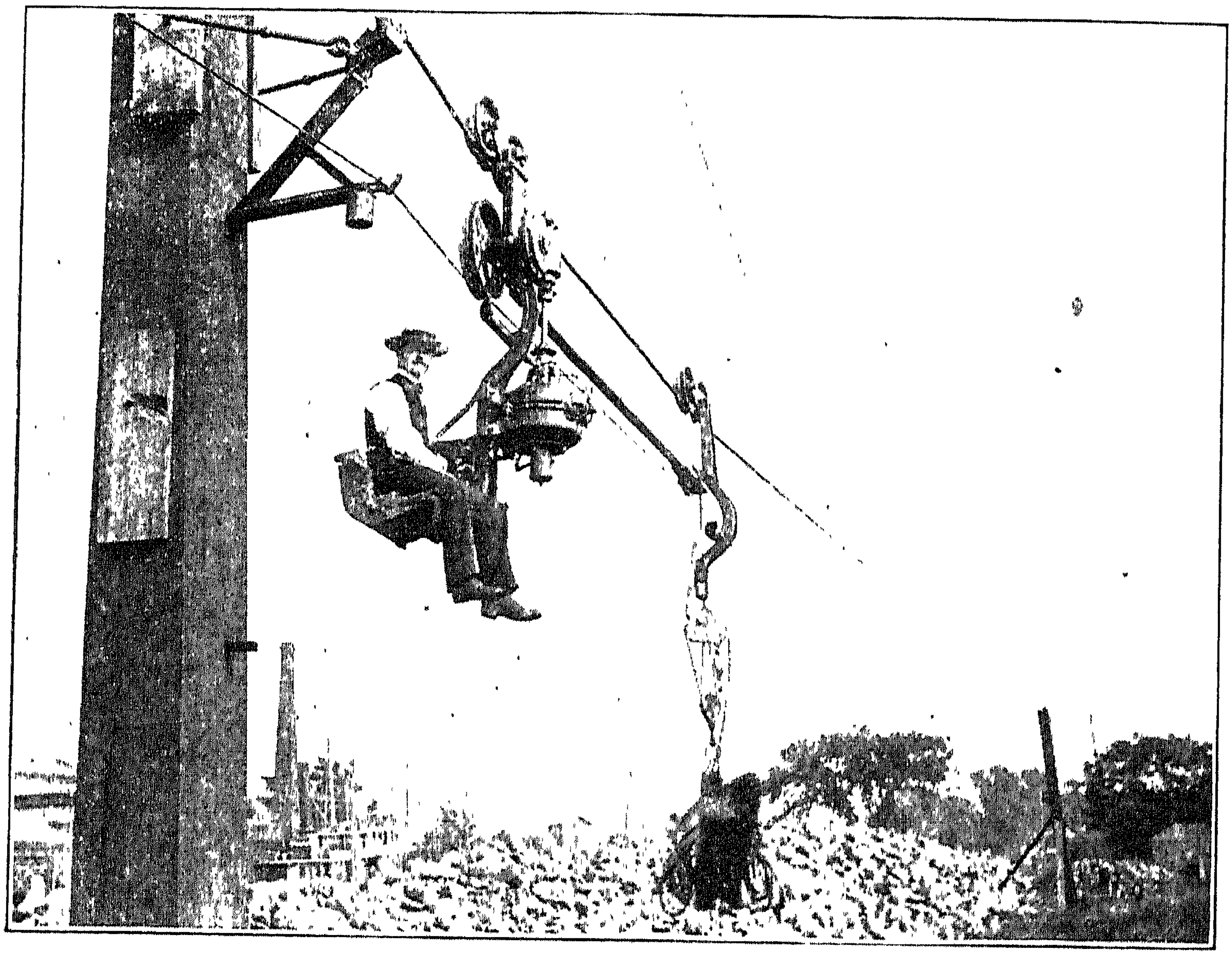

FIG. 1. First Test of Logging Motor.

In the excellent article on "Railways in the Air," published in a recent number of *The Strand*, the writer states: "Two stout wire carrying ropes are laid parallel on standards of wood or iron and then stretched tightly *in a straight line.* (These words are in italics.) Aerial rope-ways cannot run around corners." This condition is due to the fact that a moving cable has a tendency to work itself out of its carrying sheave, unless the line of the pull of the cable is straight. This fact suggested to me the necessity of the traction cable being stationary. It was a natural advance in the line of thought to note that if a sheave would transmit sufficient power to haul logs a distance of half a mile from the same, that it would be even more efficient if the power applied to the sheave was near by, and accompanied the load on its travel. As an electrician, the cables of the steam rig naturally suggested to me conductors for an electric motor that would operate the sheave. Such a motor admits of the traction cable being stationary by passing it about the sheave several times and anchoring it at both ends; thus, the motor winds in and pays out the cable, on the principle of a capstan. The fact that the traction cable is stationary, and that the lower bracket catches the cable as the motor passes, makes a system of this kind the only one that can be operated upon concave and convex curved lines.

One of the essential features of the steam cableway is having the traction rope always parallel with the bearing cable. The disregard of the direction of forces in other cable systems has been one of the main causes of their failure. On approaching a support the cable naturally sags, and the carriage has to be propelled up an incline. If the grade of the cable is steep, as it is in practice, and the power is applied in a horizontal direction, the resultant force will neutralize the pull, and the carriage will stop. Cableways, operated by horses upon the ground, pulling the carriage on the cable, have accordingly been inoperative. It was important, therefore, in the electric cableway, to have the traction cable always parallel with the bearing cable. Supposing the incline of the cable to be raised until it is vertical, we would then have an elevator; the bearing cable being the guide, and the traction rope the hauling rope, the motor being on the elevator car instead of at the top or bottom of the shaft. It is this feature that enables this system to operate on grades that would be impracticable by other methods.

This system consists of a carriage with grooved wheels in tandem, that move upon a cable or suspended trackway. From this carriage is hung a frame, pivoted to the carriage so that it can maintain a vertical position regardless of the grade of the track. This frame holds an electric motor, preferably of an iron-clad cylindrical type. The motor is geared to an elliptically grooved sheave. A steel cable is wrapped around this sheave two or more times and is anchored at both ends. For the sake of economy in conductors, the upper or bearing cable is insulated from the lower or traction cable, and is used to carry the electric

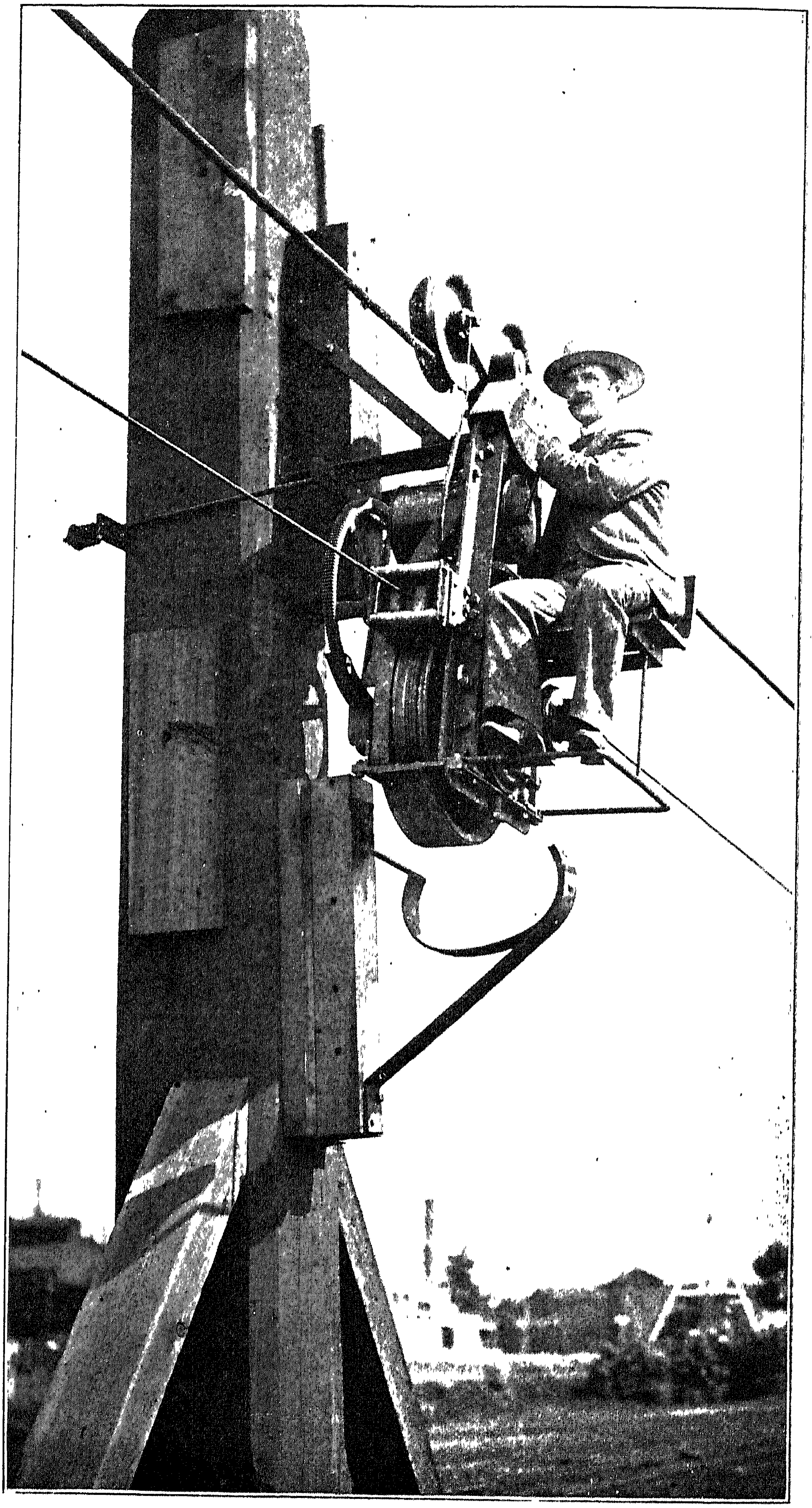

FIG. 2. "Finow" Canal Motor.

current. The carriage is insulated from the suspended frame and motor. An insulated wire is attached to the carriage and conveys the current to the rheostat. The other pole of the rheostat is connected with a convenient part of the suspended frame. The rheostat is designed to control the speed and reverse the current. A circuit breaker is put in circuit. The current from the generator passes along the bearing cable to the carriage, thence through the insulated wire, through the rheostat, through the motor, to the frame of the motor, thence through the traction cable, back to the generator. At intervals along the line, connection is made between the traction cable and the ground. A bar of copper-coated iron is buried at the foot of a tree or post to which the cable brackets are attached. A well bonded copper wire extends from this ground plate to the lower bracket, upon which the traction cable rests. In swamp and canal service the plate is buried well in the moist earth. A most marked difference in the resistance is noted when the ground connections are disconnected. When connected, the resistance is the same as if the traction cable was the same size as the bearing cable.

In making the first saddles to support the cable, they were designed for movable brackets, which can be easily put upon trees and removed to other trees when the line is changed to a different location. These saddles have a U-shaped clamp that goes over the cable, and is bolted down with wedge-shaped bolts. Under the saddle is a petticoated recess, designed to shed rain-water from the insulation placed between the saddle and the bracket to keep the current from grounding or short-circuiting.

This develops a new feature in insulation. It appeared that many of the materials ordinarily serviceable for insulating were not available, owing to the fact that often a rolling load of 10,000 lbs. or more passes over the brackets, producing a grinding and crushing effect.

Lava, hard rubber, micanite, shellac, mica and its products, glass, porcelain, ozite and all products of rosin, proved to be too brittle. Vulcanized fibre was finally used and proved quite satisfactory for a time. As only 220 volts are used in logging plants, and as it is an advantage from a construction standpoint to have the insulation as thin as possible, sheets of fibre ⅛″ thick were used. It was found that although this insulation was protected from the rain, by being shellaced and covered by a petticoat, after being exposed for some time, it would lose considerable of its resistance, and while some of the brackets could be passed by the electric motor, the heavy load on others would cause a short circuit through the insulation. This was averted by painting the saddles, brackets and fibre with insulating paint, and by increasing the thickness of the insulation to $\frac{1}{4}''$ and using fibre that had been solidified under unusual pressure. This was found to work all right.

The saddles for the plant for the Erie Canal towing test, referred to hereafter, were made so that the tread of the bearing wheels would leave the rope, and the wheels would pass over the saddles on their rims, guided by flanges cast upon the saddles. On curves these flanges were made concave or convex as required. These saddles worked excellently; and the motor passed over them easily and satisfactorily. These brackets were insulated with ozite and vulcanized fibre, and painted with insulating paint.

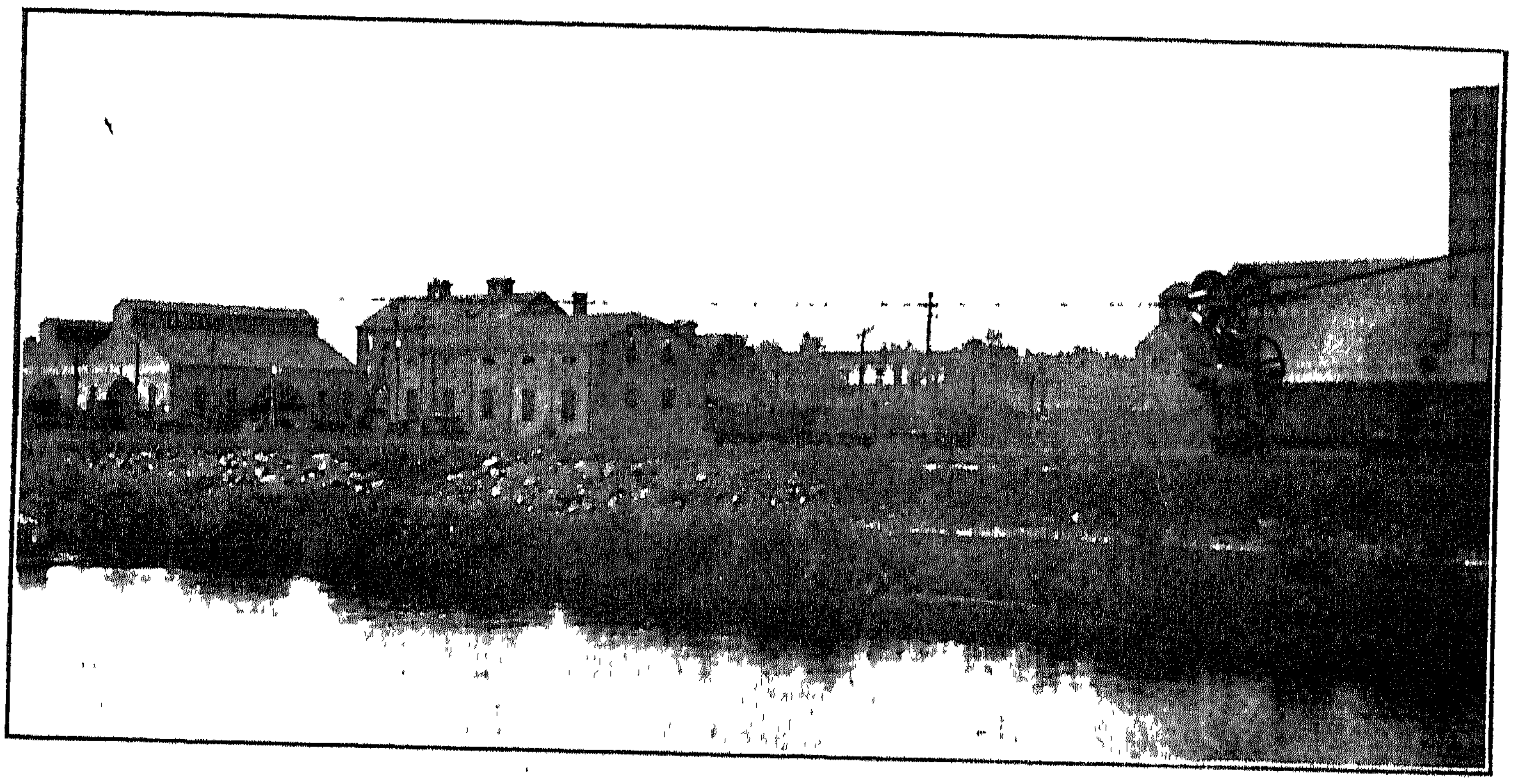

FIG. 8. "Finow" Canal Motor on Cable Line.

Work in swamp logging demonstrated that small short saddles are all that are needed, even for deflections in the line of from 20 to 25 degrees. The needle was much simplified by attaching to the brackets an insulated cone-shaped pin, over which the saddle is placed, by having a cone-shaped recess in the under part of the saddle to fit the pin. This recess also acts as a petticoat to protect the insulation. The question of insulating the cone-shaped pin was an important one. Vulcanized fibre could not be molded upon the pin. A material was needed that, while having a high resistance, would adhere to the pin, and that would stand a great crushing strain. It should be preferably non-hygroscopic, and show a minimum absorption of water.

Insulated trolley hangers were secured, that showed an insulation resistance measured under 150 lbs. vertical stress above 300,000 megohms, and after sprinkling with water one-half hour, measuring immediately above 300,000 megohms. After again sprinkling with water twenty minutes, they measured immediately above 300,000 megohms.

Tested for absorption after soaking in the water four days showed weight of 312.9 grammes; weight as received 312.7 grammes; absorbed 000.2 grammes. [Tests by Stone and Webster.]

In the insulated stud made for the saddles, the breaking strain measured over 35,000 lbs. At that point the insulation showed no signs of giving way, and the same stud was subsequently used for regular work. The instrument used for measuring the crushing strain measures only 50,000 lbs. It was thought best not to test above 35,000 lbs., which was more than needed in any service it would be required to perform. The pressure was put upon the top of the saddle and the bottom of the stud. As the thickness of the insulation is over twice as great on these saddle pins as was used on the trolley studs tested, the resistance should be at least over twice as great. [Test by Pope Mfg. Co.]

The best steel cables for cableways are the interlocked and patent locked wire rope. These are almost as compact as solid bars of steel, and yet can be easily coiled by hand in coils four feet in diameter. A simple coupling is used to connect the cables. The wheels of the car pass over these couplings so smoothly that the rider on the motor scarcely notices the fact. These points of connection are as strong as any section of the cable. An advantage in these interlocked cables is that they present a smooth surface of comparatively flat steel, which wears a great many times longer than the ordinary cables whose surfaces present round wires that wear through and unravel. These cables are made to bear much greater strains than the ordinary cables, and being so nearly solid they make much better electrical conductors.

The traction cable is made of $\frac{5}{8}''$ or $\frac{3}{4}''$ specially strong "19 wire" steel rope, with a soft iron wire core, in place of hemp, which is ordinarily used. This increases the conductivity. One of the most remarkable results in practice in this system is the fact that the traction cable does not have to be pulled very taut, in fact a sag in the cable seems to be of no disadvantage, as the motor does not tighten the line far ahead, even when doing con-

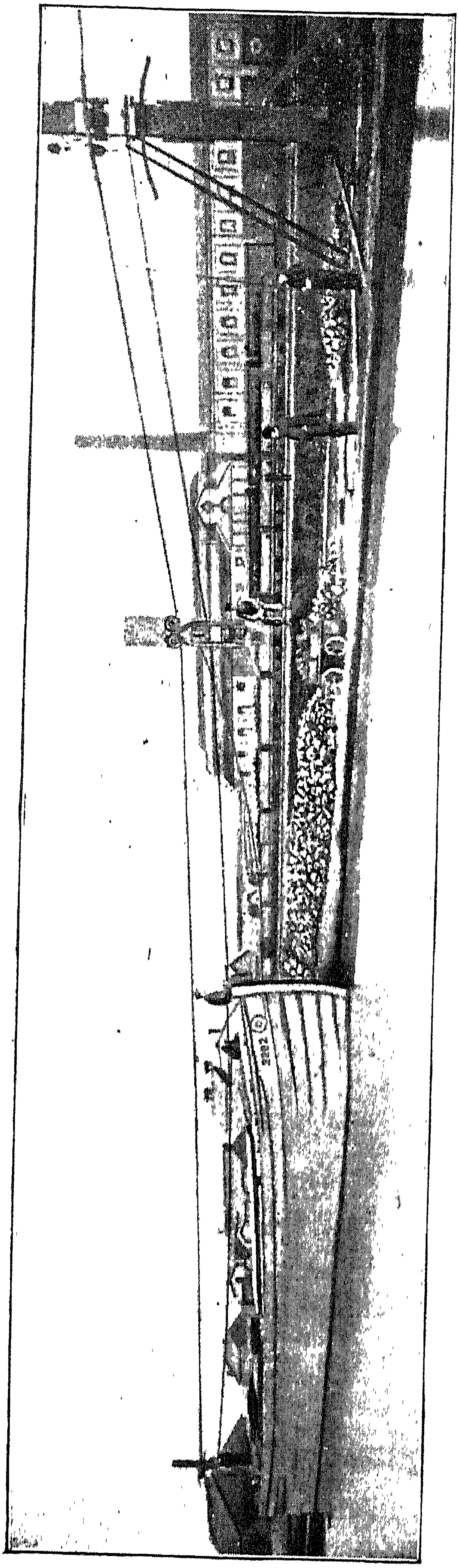

FIG. 4. Hauling Canal-boat at Trenton, N. J.

siderable service. The sag adds to the weight of the cable and to the friction on the brackets, and these two resistances act as an anchor for the traction cable, independent of the terminal anchorages. For example in the case of a trial plant for a German canal the resistance to be overcome by a motor, or its "draw-bar pull" was to be 645 lbs. Now at one pound per running foot of traction cable, the influence of the motor pull would only be felt 645 feet ahead of the motor. Therefore with motors distributed 645 feet apart, each one practically has its traction cable anchored from the motor ahead, and,in consequence the combined pull of all the motors is not exerted upon the terminal anchorage.

In the first plant, the clamps on each of the lower or traction cable brackets were made with steel jaws, with springs under them, such as are used on grip-pulleys. When the traction cable was pulled the clamps gripped the cable,and when the motor lifted the cable, on passing the bracket, the jaws released the cable. These clamps were found to be unnecessary.

In canal practice the terminals will be ten miles apart with tension stations every two miles. At the terminal stations rotary transformers will transform the high voltage alternating current to 500-volt direct current, and send the same each way a distance of five miles. Where the traffic justifies, a line will be placed on each side of the canal, when the insulated or bearing cables will be connected at intervals to feed each other. The anchorage of the traction cable will be made with a series of clamps, and the motors will be passed through them as canal boats through locks. At the end, the motor is released from its traction cable and is conveyed across the canal on a cable, or where masts are allowed on boats in the canal, by a hinged trussed track that can be opened like a gate, or raised out of the way. The handle of the rheostat is easily controlled from the boat by a cord attached to the handle. When the cord is pulled from the opposite direction to which the motor is to be run, the current is admitted in the proper direction, and the motor proceeds. When the cord is released, the handle flies back to a vertical or cut-off position, and the motor stops. When two boats pass, they exchange motors by simply exchanging tow-lines and controller cords.

The first test of canal boat towing with this system was made on the Delaware and Raritan Canal, at the Trenton Iron Works. The motor was made to go over concave and convex curves and up and down grades while towing the boat.

In reference to the test of canal boat towing on the Erie Canal, at Tonawanda, it is not necessary to make any apologies for the system. Superintendent of Public Works Aldridge, in his report to the Legislature, unqualifiedly endorsed the system and stated: "Early in the season of 1895 application was made to me to officially designate a part of the Erie Canal for the proposed test of the efficiency, economy and practicability of the so-called 'Lamb System' for improving the present system of towage on the canals of the State. The location selected was a piece of canal about one and one-quarter miles in length at Tonawanda, N. Y. The purpose was to select such a portion of canal as would embrace as many practical obstacles to the success of such a plan of towing as could be found anywhere in a section of canal that length."

In the report of Chas. R. Barnes, electrical expert for the Public Works Department of the State of New York, he sums up by saying: "The electric towing system appears to present so many meritorious features that I have no hesitation in endorsing it as the system deserving preference over any other hitherto experimented upon, or likely to be devised in the near future."

So short a time was given in which to construct the trial plant that existing models had to be copied. The motor was over 9 feet in length; it weighed 2,213 pounds. The elliptically grooved sheave was driven by a worm-gear. The voltage, which was gotten from a trolley line, fluctuated from nothing to 500 volts, but seldom equalled the latter amount. The bridges under which the motor had to go were very low, and had to be ap-

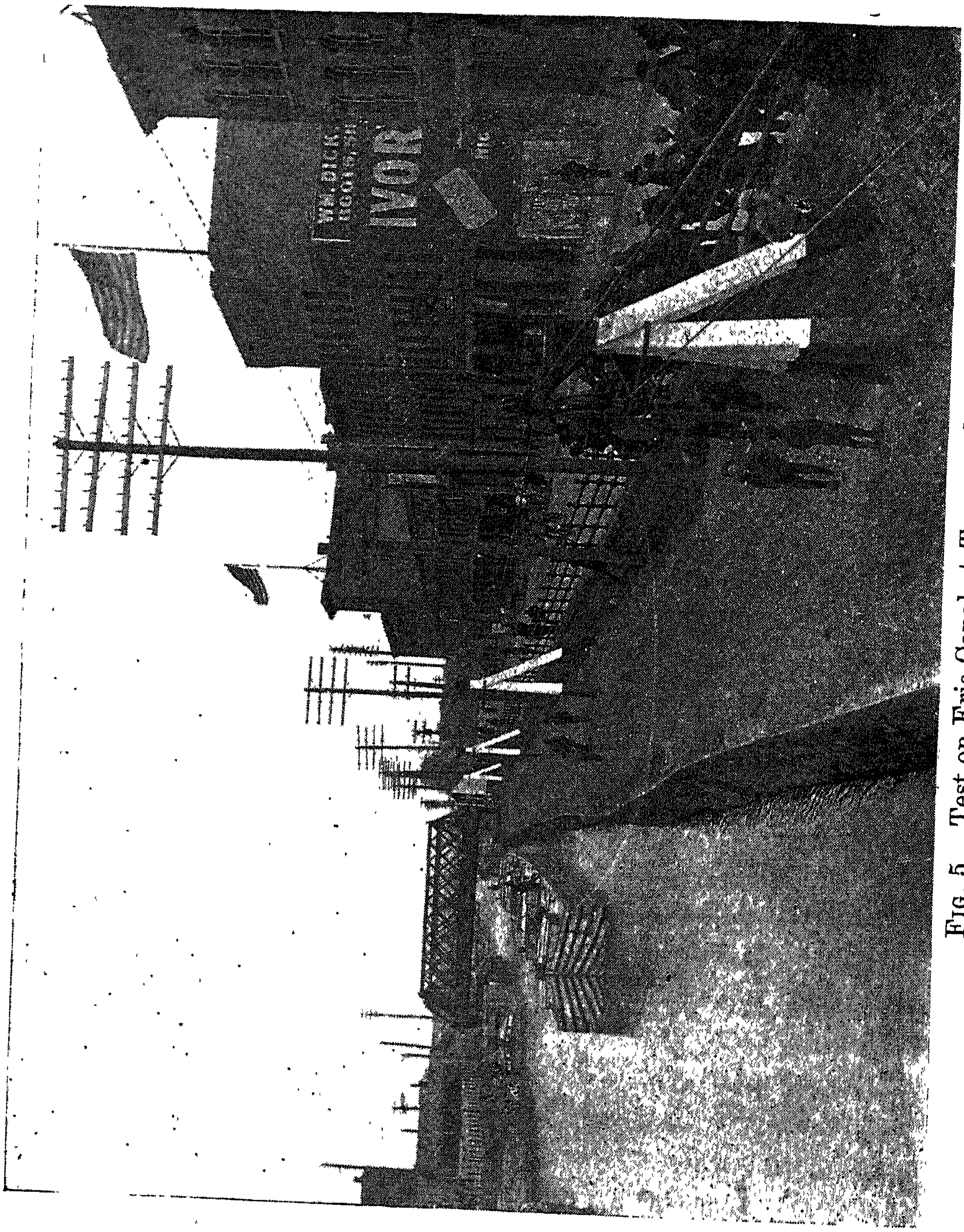

FIG. 5. Test on Erie Canal at Tonawanda, N. Y.

proached by reverse curves on a grade of about 20 degrees. Trenches had to be dug next to the abutments to give room for the motor to pass under the bridges. Both convex and concave curves had to be passed over, and at one point the deflection was about 30 degrees. In spite of the difficulties, the trial showed that the system performed economically and efficiently all that it was designed to accomplish.

In the plant recently constructed for trial on a German canal, the motor has been shortened to less than five feet in length; its weight reduced to 1,300 pounds. The worm-gear has been avoided by a double reduction direct gear, gaining 50% in efficiency over the worm-gear, and the elliptically grooved sheave has been placed about the cylindrical electric motor, getting a large bearing surface and increasing the efficiency accordingly. At the test made at the Trenton Iron Works this motor, using a 5 horse-power Storey motor, wound for 500 volts, and going at the rate of 2.3 miles per hour, pulled 800 pounds when having the use of only 220 volts. This shows a remarkable efficiency, which is due to the mechanical principles utilized, viz., hauling the motor along by a fixed rope, attached to a capstan operated by practically a winch.

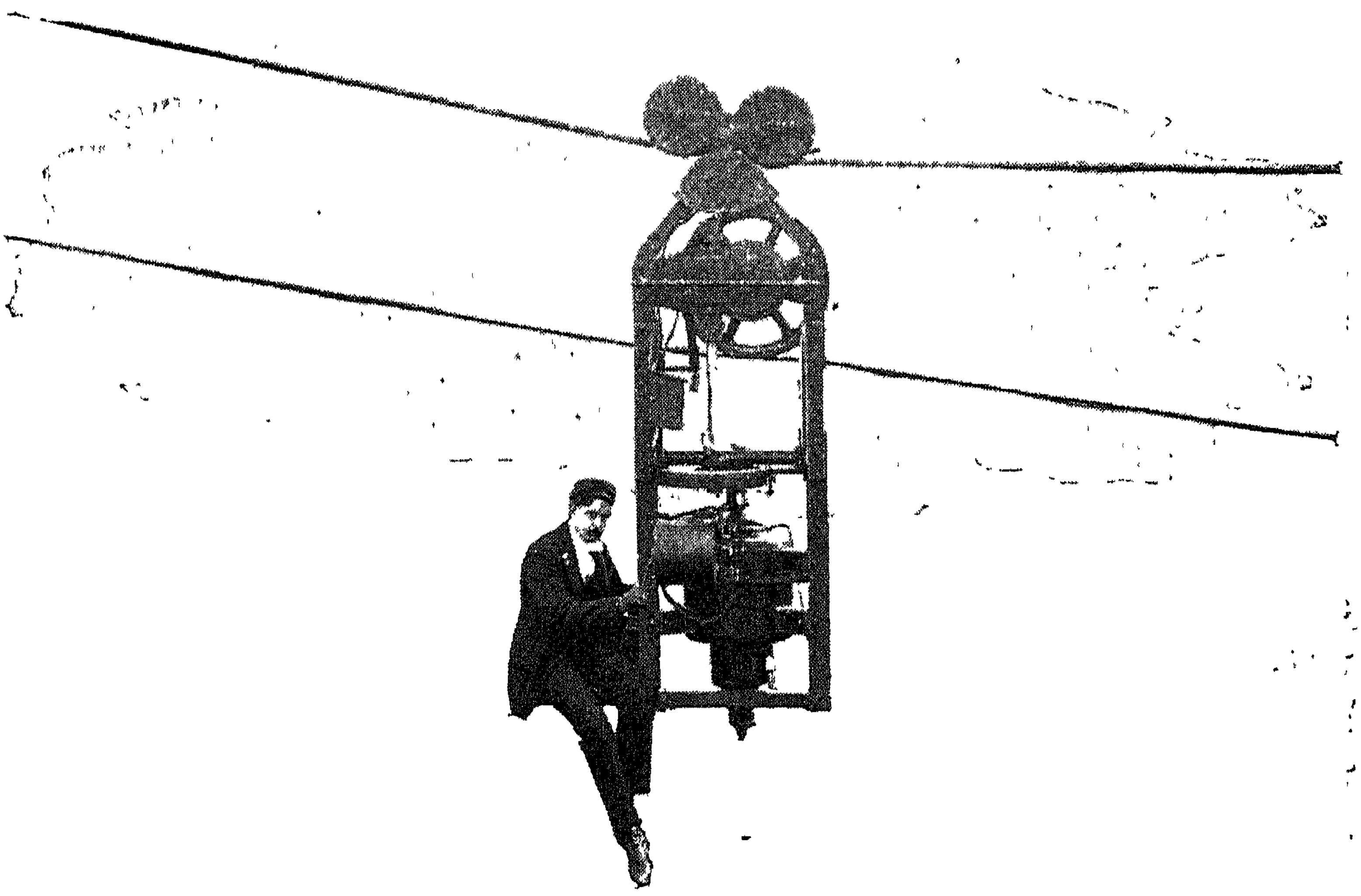

FIG. 6. Motor used at Tonawanda.

The uses to which this method of telpherage can be put are so numerous that I will not attempt to give descriptions of plans that have been, and are now, being made for various parties, for such services as fortification work, rice culture, mining plants, ship building and sewer excavating plants. I will confine my descriptions to completed work.

Possibly the most universally serviceable application that has been made of the system is traversing motors with double hoisting drums for quarry purposes. These motors are to go on 700 feet span cableways. Each of these cableways has one end stationary and the other is movable on a curved track. They are designed to lift 10,500 pound rocks at the rate of 50 feet per minute and traverse at the rate of 300 feet per minute. At a test at Trenton made upon a temporarily erected cableway we raised 6,600 pounds, and ran on the cable at the rate of ten miles per hour, part of the time going up a grade of over 15 per cent. There will be no difficulty in these motors raising over 10,500 pounds and running 300 feet per minute. A 15 horse-power Storey motor is used. The rheostat reverses the motor and regulates the speed. A band brake also is used to regulate the stopping. This is controlled by a lever in front of the motorman. There is a safety brake to be used in case the band brake should fail. This is operated by a wheel. The shoe of this brake clamps the upper cable. It is attached to the car proper, and with the wheel handle oscillates with the carriage as it climbs or descends grades. A lever in front of the motorman is used to control the speed of the drums that raise and lower the skip. A friction clutch, controlled by a wheel handle, disconnects the traversing sheave gear and engages the hoisting drums or vice-versa.

In a place within reasonable distance of an electric plant having surplus power, these electric cable hoists can be erected and operated for a comparatively small cost. In contracting work, where electric lights are also used, these cable cranes can be used to great advantage. In other places the small generating plant necessary to operate these motors will add but little to the expense of an outfit.

Those who think that electrical machinery is of such a delicate nature that it is only serviceable for cities of advanced civilization, should go to the Dismal Swamp, and see a so-called dainty machine doing as rough and dirty work as any service to which a machine could be put. He would see the laborers, over their knees in mud, sawing down giant trees, and hear the woodsman sing: "Stand from under, she's saying good-by to her neighbors." With a crash that throws mud and water high into the air a tree will fall and fill a space with broken limbs, embedding itself well into the mire. This means work for the motor. Logs are to be drawn from their beds, and when the ammeter in the generator room on the scow, for an instant runs up, possibly to

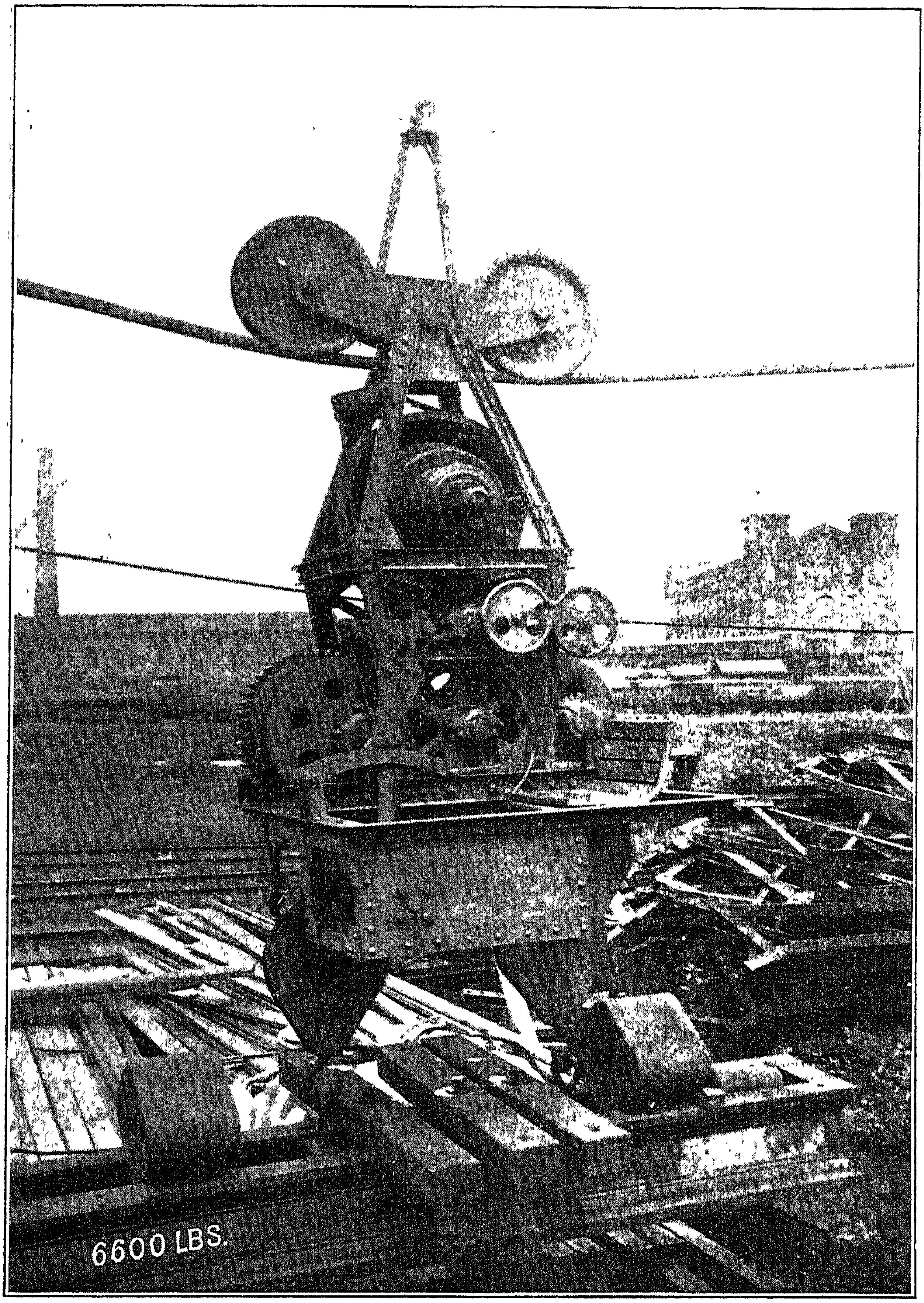

Fig. 7. Loaded Crane on Cable.

a point of overload, it is the motor overcoming the suction in drawing out a buried log. With the voltmeter standing at 220 volts, you would see the needle momentarily go to 35 amperes and then drop to about from 10 to 16, depending upon the size of the log. As the cone over the end of the log strikes a stump or a cypress knee, the needle flies to about 20 and then back, and as the log dives off from an obstruction it may be crossing, the current drops to zero momentarily. Finally when the log reaches the tail-tree, about 20 amperes is recorded as the log rises from the ground and hangs suspended by the hauling cable. This cable is reeved through a sheave, which is attached to the tail-tree fifty or more feet from the ground.

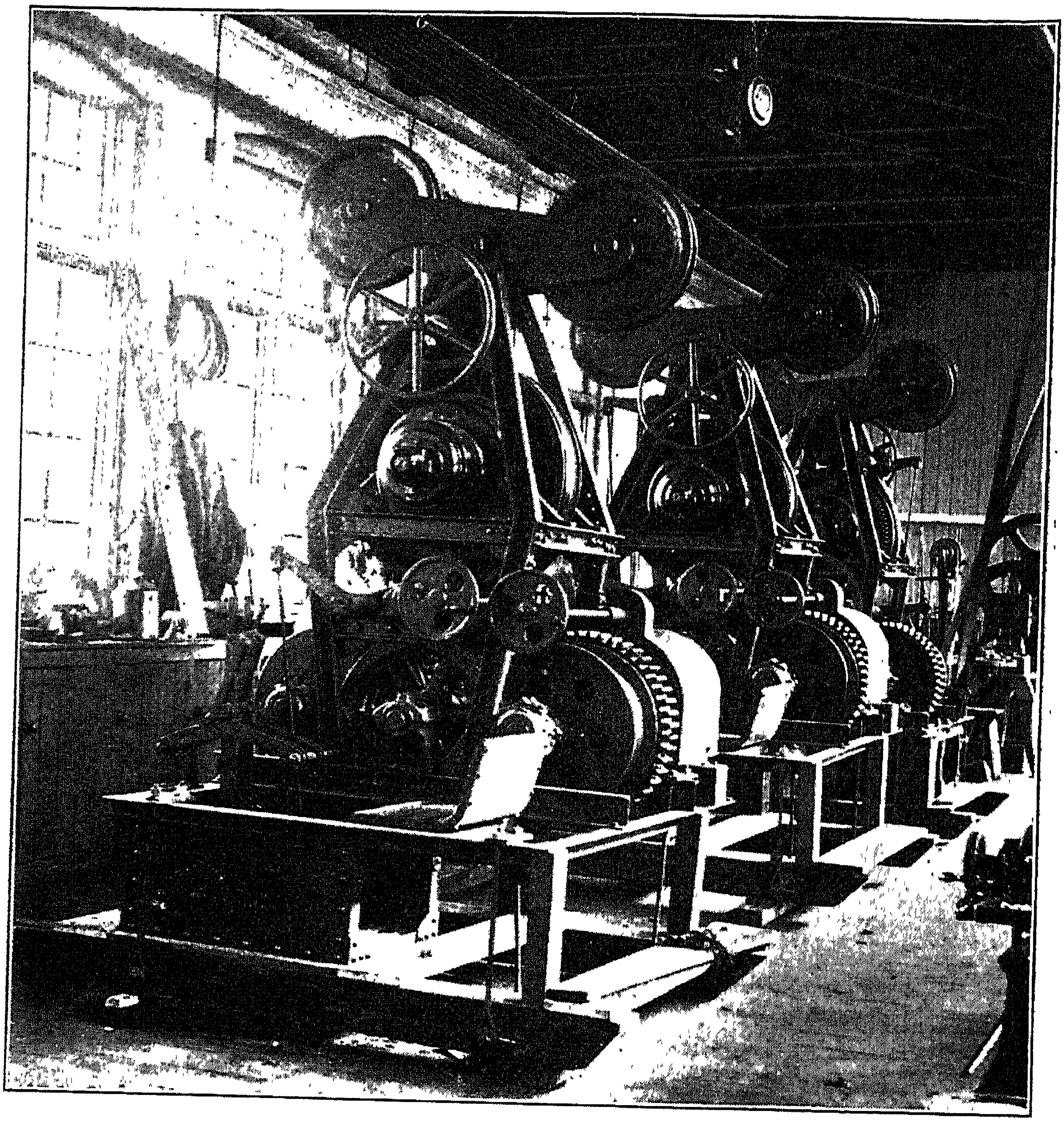

FIG. 8. Crane Motors in Shop.

After a number of logs are drawn to the tail-tree, they are transported over the cableway to the terminal on the banks of the canal. Reading the ammeter as the log comes in we see it start at about 5 then go up to 12 or 14, as it crosses the bracket saddles, then go down to 5 again. In this process of transportation, one end of the log is suspended by a car on the cable. The

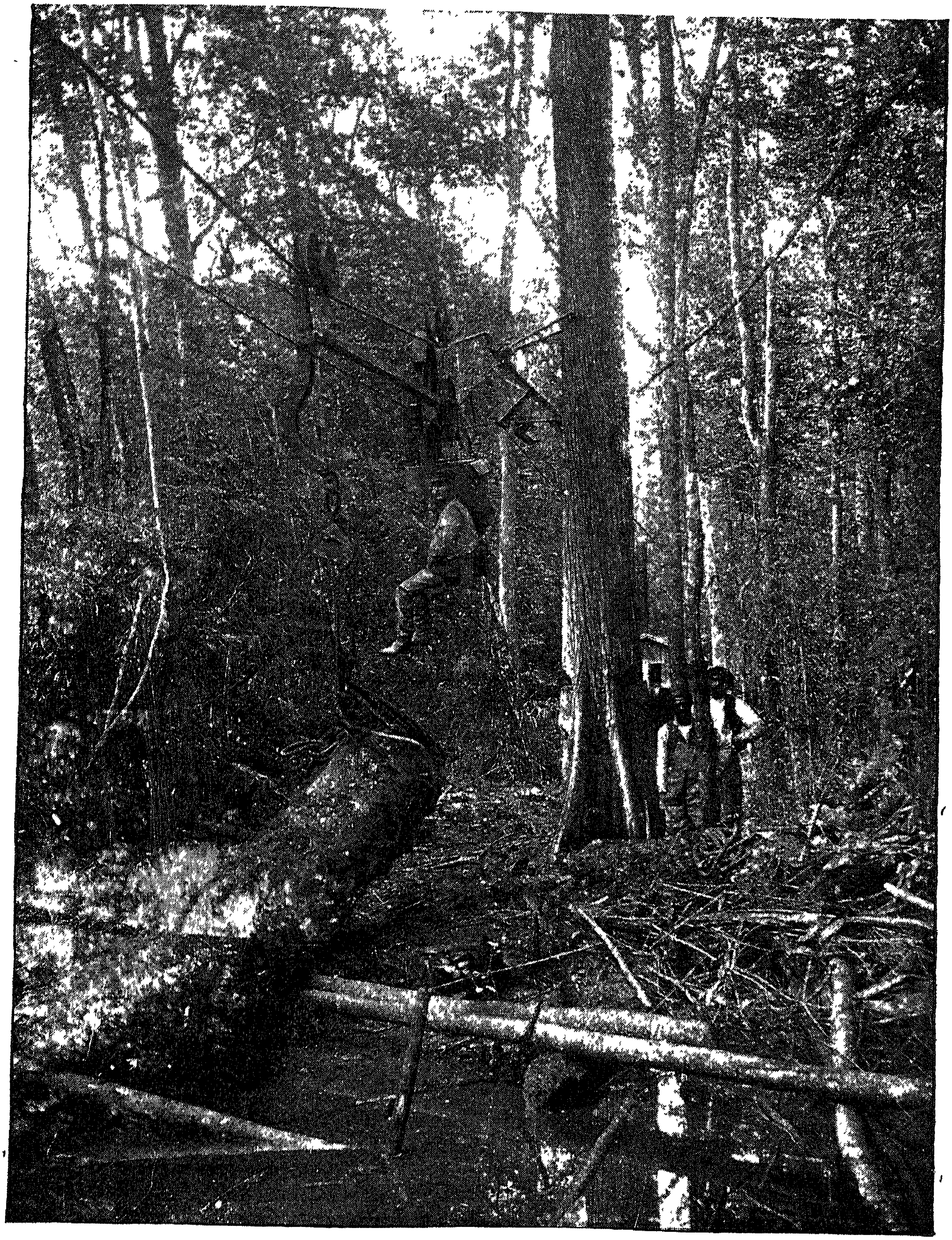

FIG. 9. Logging Motor working in Swamp.

end of the log is raised from the ground by holding fast the bight of the grip-block rope and going ahead with the motor. The block is attached to the car, when the same results are produced, as if the power was applied to the rope direct. When the end of the log has been raised to the proper elevation, the grip holds it from falling, and the rope is coiled and placed on the tongs which holds the log, and after getting a couple of cars loaded you are ready to carry your valuable logs from one of nature's worst fastnesses to a point where they become valuable to mankind.

The question has been asked, "do you require expert help about these logging plants?" In answer, I would say that I am satisfied with my superintendent. He has spent his life in swamp logging, and has had no chance for education, much less scientific studies. When I assembled the generator, the first time that I put up the plant, he put on a pair of rubber gloves, not wishing to run any chances of getting a shock, even if there was no fire in the boiler. While testing the plant a fuse blew out on the generator, and one of my negro help started on a run into the swamp and never returned again to work. I afterwards heard that he stated: "Mr. Lamb can't fool dis nigger, I done worked on the government dredge boat, and knows what a dynamite machine is."

In spite of the lack of electrical information of the logging crew, no inconvenience has been occasioned on that account. All features of insulation are provided for before the plants are shipped. An ordinary steam engineer acquires quickly the necessary information for running the dynamo. The motor is shipped with all parts adjusted, and the extent of the motorman's duties is simply to push the handle of the rheostat according to the direction he wishes to go.

The light first cost, the high efficiency, the ease with which it can be operated by ordinary mechanics, portend for this system an important place among the useful applications of electricity of this century.

DISCUSSION.

THE PRESIDENT:—This paper presents a very novel branch of our profession, one that few of us have paid much attention to, and it is interesting, I think, to note the fact that the simple methods of the trolley, that is the simple current-carrying wire from which the current returns by a ground or cable which is grounded, have replaced the earlier method of telpherage in which the sections were alternately positive and negative, and as Mr. Lamb pointed out, require the train of telpherage cars to bridge across from one to the other. That seems to be a radical improvement and enables a much simpler mechanical construction to operate successfully with the electrical conditions. In fact I should think that limitation of telpherage requiring a long train of telpherage cars to be operated in all cases was a very serious one as Mr. Lamb indicated, and would naturally prevent its general introduction. But the very simple methods employed by him which have been very clearly and completely set forth, I think will be appreciated. The subject is open for discussion.

MR. TOWNSEND WOLCOTT:—I would like to ask Mr. Lamb a question. I suppose that the insulation resistance of 300,000 megohms is meant for 300,000 ohms, isn't it?

MR. LAMB:—That is from the expert's report.

MR. WOLCOTT:—300,000 megohms?

MR. LAMB:—I recognize that a megohm is a million ohms. That is copied from his report.

MR. WOLCOTT:—It would be interesting to know how he makes it so many thousand megohms. May I ask what the efficiency of the worm gear was?

MR. LAMB:—I think we lost about 50 per cent. by the worm.

MR. WOLCOTT:—You think the worm gear lost about 50 per cent?

MR. LAMB:—Yes sir. We lost power not only from the fact that we used a worm gear but also from the fact that we had 100 per cent. more weight.

MR. WOLCOTT:—I mean what is the efficiency of the whole motor with the worm gear. You say the efficiency of the whole motor with the spur gear is 50 per cent. greater than the worm gear.

MR. LAMB:—We figured that we had an absolute loss of efficiency of about 50 per cent. on account of our worm gear. We doubled the capacity of our motors by changing to direct gear due to the fact that we get a very much better general arrangement with less friction on other parts, and also we get a very much lighter motor. We had however only 220 volts and the motor was wound for 500 volts, so we could not get an exact record for that particular motor.

THE PRESIDENT:—Do you reckon that, Mr. Lamb, the improved arrangement consumed very much less current?

MR. LAMB:—It consumed very much less current. Of course the voltage in both cases was different, but taking the watts it shows a very much better efficiency.

THE PRESIDENT:—That is a perfectly good method of reckoning it, much better perhaps than some abstract mechanical test of the efficiency of gearing.

Are there any other remarks on this subject? It is certainly one which deserves discussion.

MR. CHARLES P. STEINMETZ:—There is one point I want to find out more about. It is stated here: "At the test made at the Trenton Iron Works this motor, using a 5 horse-power Storey motor, wound for 500 volts, and going at the rate of 2.3 miles per hour, pulled 800 pounds when having the use of only 220 volts. This shows a remarkable efficiency." I do not see that it shows any efficiency at all since no current is given. The current has to be known to get the efficiency, and since it is not given, the statement made in the paper, on the remarkable efficiency, is not proven.

MR. LAMB:—I could insert there the amperes. It amounted to 5 horse-power when you take into account 220 volts.

Mr. Steinmetz's question can be answered in this way. That motor was wound for five horse-power and it pulled 800 pounds going at the rate of 2.3 miles an hour. No relative statement of efficiency was made, but it showed a most marked efficiency and gain over the other motor which never could have pulled 800 pounds at 2.3 miles an hour with the same amperes and voltages.

MR. STEINMETZ:—It merely shows that the second motor has a larger capacity, or larger power than the first, but gives nothing regarding the efficiency, as long as the actual amperes are not recorded.

THE PRESIDENT:—Have you any figures Mr. Lamb, in regard to the actual current input?

MR. LAMB:—I can give the amperes, but I have not them here.

THE PRESIDENT:—Mr. Steinmetz brings up the point that you cannot calculate back from the result you have got; that begs the question; that you have got to have the actual figures of input and output. You have the figures of output, but you must also have the figures of input in order to calculate the efficiency.

MR. JOSEPH SACHS:—I believe Mr. Lamb should give us the efficiency of the machine from the input at the motor to the actual pull and work done in moving along the cableway by that same motor. The spur gear and motor efficiency can easily be approximated. It would be interesting to hear something about the work-doing ability of his elliptically grooved cable-drawing sheave, which constitutes one of the basic elements of this system. I have been interested in this subject for some time and have heard a great many opinions pro and con regarding that sheave, and I would like to hear from Mr. Lamb personally regarding its efficiency and also the wear and tear upon the pulling cable. If we can approximate the losses in those two elements we can get quite close to the total efficiency of the complete machine.

Mr. Lamb:—Mr. Sachs' point is well put. The efficiency of the elliptically grooved sheave is a very important feature of this form of cableway. The electric motor, of which you have seen the picture, operating in the swamp, has been running for about a year and a half and I do not see any wear on that cable. If you had that same cable winding up on a drum, you would have a grinding effect and it would be increasing in size and lessening in size and winding over itself all the time, and there would be more wear upon it than if there is simply a couple of turns that play upon this elliptically grooved sheave which is guided and kept from riding, one cable on the other, by rollers. I do not see any reason why that cable should not last for four or five years at least, without any material wear at all. It is an inexpensive piece of mechanism anyway. In regard to the matter of the exact efficiency, which probably ought to have been spoken of first, I cannot give the facts, for the reason that we had, as I stated, a motor wound for 500 volts, and we only had 220 volts current.

Mr. Sachs:—You got a certain amount of energy laid up by drawbar pull, feet per minute or feet per second, whichever way you might take it, or miles per hour, and what I am trying to get at, and what I think Mr. Steinmetz would like to get at, is simply the approximate energy from the input energy, and the actual work and output done by the machine. We have two sets of spur gearing there. We can approximate their efficiencies, and you have got the cable pulling sheave which we cannot approximate, because we do not know the exact facts, which you can probable give us. There must be more or less loss there, and probably a good deal, because your whole tractive effort must be gotten between that sheave and the cable. You must get slip there, and you must get wear and tear on the wheel and on the cable both. I think if we can get those two points we can get very nearly at what we are driving at. The fact that the motor ran at 220 volts simply shows that it ran slower, and when it receives 500 it would run faster.

Mr. Lamb:—Mr. Sachs can get the information he wants from the Superintendent of Public Works' expert electrician, Mr. Barnes's report on the Tonawanda test as to the first motor. We have not got the full data for the second.

Mr. Elias E. Ries:—It seems to me that this whole discussion is greatly out of place. I do not think there is a gentleman present in this room to-night but who upon viewing the diagrams which we have seen upon the screen can see the whole operation very clearly and make due allowance for such losses as are likely to take place in such an installation. It seems to me we have a new proposition to deal with this evening, that is to say, a method of transportation or of conveyance by means of an overhead motor carriage suspended from a cable. So far as the efficiency of motors is concerned, we all know pretty well what they are capable of. Whether this first motor has reached the stage which is within practical range to-day or not, is a question of very little importance. The only new features so far as losses are concerned which we have to contend with in this matter, it seems to me, are those involved in the frictional winding of the cable upon the drum and the constant ascending, you may say, of the carriage upon the cable, which has already been referred to, and the losses due to the particular kind of gearing which are necessarily introduced. All of these things, as has been stated by a previous speaker, can no doubt be eliminated more or less with further progress in this direction. The construction of the line, etc., will probably introduce some improvements later on, and so the questions of efficiency are very minor questions as compared with the new results produced.

It occurred to me, while Mr. Lamb was reading his paper, that if this system is as successful as his statements seem to indicate, that it might be extended to a great many other applications than that to which he already has applied it. For instance, some modification might be devised for the purpose of using such a system for ordinary conveying, excavating and such work as that, in which this motor, if you are going to use a motor suspended from the carrying cable to propel itself by a traction cable coiled around its own drum, may be provided with a supplemental drum operated by that same motor, while stationary, for the purpose of raising and lowering cars and boxes filled with excavated material, and then when they are raised, the main propelling motor can be switched in and material so excavated can be carried off to a distance. That, for instance, is one application that suggested itself to me this evening while listening to Mr. Lamb's paper. And then it seems to me that it might be applied to a good many other purposes, for instance in agriculture. Of course those things would require more or less development; but the point I wish to make is that what the INSTITUTE ought to discuss, if they discuss the matter at all, should be with regard to the possibilities of this system of cableways which Mr. Lamb has explained, and not harp upon the merely minor points of efficiency or lack of efficiency, because those are well known things that we can deal with without that discussion.

MR. MAILLOUX:—I am not so much interested in the efficiency part of the problem as I am in the insulation part, and I would like to know something more about the fibre insulation which Mr. Lamb says he has used with success. Some ten years ago there was a system of electric railway signaling in operation on Staten Island, which system comprised a small dynamo on the locomotive, and required the rail to be cut into sections or blocks and insulated. I was called in consultation in connection with the matter with a view to overcome very many difficulties, (one

hich, by the way, was the capacity of the apparatus to do
k under all conditions, such as the vibration of the car,
, although the principal difficulty was that of maintaining the
ation of the track and of keeping the sections electrically
rate and distinct. I think that every material under the sun
seemed at all available was tried, and everyone of them
d. Fibre was the last resort and many experiments were
e with all kinds of fibre, and used under all conditions, even
e specially, but we could never depend upon it. The best
ts were obtained when the fibre was in the form of plates
ted between the fish-plates, with bushings. Very particular
was taken in designing the mechanical parts of the outfit so
make it absolutely stiff and to avoid the slightest motion.
as everyone familiar with railroading knows, it is impossible
ake any sort of a mechanical joint in a rail as good as a rail
has no joints. That is the reason why welding has been in-
ced, so as to make continuous rails. In a short time, in fact,
y short time, the material would give out mechanically, be-
abraded and worn and would absorb moisture. The in-
y of the fibre would be destroyed and it would no longer
its purpose as an insulator. I very much fear that some-
like that is likely to occur with any known form of insul-
subject to severe mechanical strains; and that is the reason
after having known of fibre being used without success in
rms and varieties as it was known up to seven years ago, I
l like to have some further information about the kind of
which is now being used with success.

to the difficulty referred to by another speaker of measuring
00 megohms, I may state for his information that it is not
a very difficult matter to measure 300,000 megohms. I had
it in two places in Europe this summer, and in both cases
done without any difficulty and without any elaborate ap-
us. In one case we had no difficulty in getting 3,750
ms per volt with the ordinary double static Thomson gal-
neter (of German make) and the scale used (with reflected
set at about a metre and a half distance. In the other case
sed the Rosenthal galvanometer with the scale about 3.5
s distant and the readings made by a telescope. I find it
so be done even in my own office at the fourteenth story of
ern "iron-cage" office building, with an ordinary D'Arson-
lvanometer having a much lower figure of merit, (showing
about 1,000 megohms per volt). But in that case I use
voltage. I use a small Crocker-Wheeler motor dynamo
an give me from 200 up to 600 volts, and it is only a
on of "piling on the pressure" until you "get there."
a hundred volts it will measure 100,000 megohms, and
igher voltage we find no difficulty in getting up to 400,000
ms. The outfit is used very often, for insulation measure-
especially for testing the insulation of high grade rubber

covered wires, and it has always worked with satisfaction, while it has the merit of enabling the measurements to be made with relatively short sample pieces such as would give no reading with lower pressures.

MR. JOSEPH SACHS:—The question of insulation, it appears to me is one that takes very much the same form as the question of efficiency; that if it does not work now it can be made to work later on. I think that if Mr. Lamb has not got the proper kind of insulation now, a little further experimenting will produce it. Now the question of efficiency is another one. Quite true, it cuts no figure in the present development. When you haul logs, as Mr. Lamb says, you have no competitor. A system of this or similar nature opens up previously inaccessible regions where other methods would fail entirely. Much of this success depends on the fact that weight is not used for tractive effects. The canal boat hauling problem is, however, one in which there are many competitors and not by any means the least is the humble mule. Then we have steam canal boats, and various methods of electrical boat propulsion on canals such as the Erie, which forms only a part of the complete route. These and other considerations are of the utmost importance. There are at least a score of electrical and mechanical methods for this purpose. Efficiency is a very important factor in all when they are being exploited to compete with other methods. Aside from efficiency Mr. Lamb might tell us why his system is superior to other similar hauling systems several of which will suggest themselves. It may be interesting to note another point which is interesting and perhaps quite as important as efficiencies or insulations; that is the regulation and control of the motor. When a motor of the type here described is used for log-hauling it is essential that the operator should be right at the motor and is therefore seated on the carriage as it would be inadvisable to place him elsewhere. In this position he has all switches right at hand. Boat hauling, however, brings in another consideration. Unquestionably the hauling method is the superior method of boat operation in narrow water-ways and far surpasses any propeller method. Mr. Lamb will probably remember a little discussion that we had some years ago regarding whether the motor ought to be regulated by a man upon the carriage itself or whether that motor ought to be regulated from the boat. I am glad to see that Mr. Lamb has come around to my way of thinking although he has not adopted my method. Our co-member, Mr. Martin, and myself, some years ago spent some time in writing "Electrical Boats and Navigation." We succeeded in making some prophecies and one of them was that the most feasible method of operating canal boats was to haul them and to regulate from the boat. Now the method adopted by Mr. Lamb comes to that point. It does away with the man upon the motor itself and probably saves his pay, which in the long run amounts to something, as the hauling of a boat through the Erie Canal takes several days. The method he describes, however, while far superior to the man being placed upon the motor, has objections, and one of them, which I would like to ask him about, is what happens when the motor slows in speed? The hauling rope undoubtedly slacks up, and certainly the regulating rope is similarly affected. There are various other times when similar conditions occur, and the boat will probably stop owing to the cessation of current in the motor. A method which seems to be more correct and devoid of the objections to the other has the regulator and switch upon the boat itself. Systems of electrically hauling canal boats, wagons and logs have been experimented with for probably the past fifteen years. Messrs. Ayrton and Perry were amongst the pioneers in this direction. Aside from boat and log haulage other applications were suggested. In one of these such hauling motors running up in a small suspended track or wireway, are connected by ropes or chains to wagons on the common roads. A recent installation now being experimented with contemplates the operation of electric motor wagons on common roads, current being supplied by an adjacent conductor. A hauling motor method, however has advantages, as any wagon may be hauled. The utilization of such carrying methods in quarries I believe is now being attempted by Mr. Lamb, and in conjunction with the motor carriage a hoist is used.

MR. JOSEPH BIJUR:—Recently I visited a country where considerable lumbering is being done, and I noticed that the lumbering is largely confined to the water-ways, and that they bring some of the more distant logs to the water by skidding them over frozen brooks and slides in the winter.

It would seem that any method by which logs could be brought to water-ways would be very valuable, but there appears to be this objection to the system which Mr. Lamb has just explained, namely, that perhaps the cableway has not sufficient capacity for carrying logs to convenient water-ways to make it worth while erecting the lines. That is, as to the cableway shown on the screen to-night, the car would take one or more logs from wherever the lumber was cut, to the end of the line, and then perhaps come back and again carry a limited number of logs to the end of the line.

If that were the case I should think that the capacity of the line would be small, unless it was so arranged that a number of cars should follow each other successively around in a circle. I should like to hear from Mr. Lamb whether there is any method for overcoming that apparent objection.

MR. LAMB:—The number of logs hauled per day is only limited by the amount of capital put into the plant. If you build a large enough generator and put your cableway on both sides of the tree, your empties go out and your loaded come in and you can bring in as many logs as you wish. But I do not want to have it understood that I have ever anticipated that this system for logging would supplant the regular logging railroads where you have to go a very long distance. The number of logs that you would haul by such a system would make the system inefficient. It is only for short distances. We do not recommend it for over two miles. But the fact of the case is that I have tried every form of logging, to load the logs after felling them and putting them on the cars in order to carry them to the mills, and there is not a system in existence to-day that in actual practice logs over an average distance of 500 feet, with the exception of the "pull boat" system, which is simply a large double drum engine that winds in and pays out a cable reeved about a large sheave anchored into the swamp. Tongs are attached to the cable, which engage logs, which are hauled in over the ground, tearing everything before them, including sometimes the cable itself. This system is not efficient. They do not haul in very many logs per day. What we are after is to get a system that will go beyond 1200 feet into these swamps that are miles deep. We get out logs near Norfolk that have been standing there for centuries that bring $20 a thousand feet at Norfolk City. They could not be profitably logged heretofore. But to go into the regions that my friend refers to and compete with streams and skidding by sleds was never anticipated. We can haul a large number of logs from a reasonable distance by having a large enough plant and enough motors.

MR. STEINMETZ:—Mr. Lamb has given us a very interesting method of canal boat propulsion. But I would like to ask one question. Why do we need two heavy cables? Why couldn't we put the ordinary trolley line over the canal and the ordinary propellers on the boat? We know all about the propeller and its action and that it will propel the boat, and that the motor will run the propeller. Why have these heavy cables instead of the ordinary trolley?

MR. LAMB:—I would refer Mr. Steinmetz to Mr. Sachs' and Mr. Martin's work on the subject, which is excellent and exhaustive, and proves that the trolley propeller is a very inefficient way of doing the business.

MR. T. C. MARTIN:—There is another point besides efficiency. As I understand it the objection of putting a motor directly on the dishpan propeller is that the banks of the canal would not stand the wash, and for that reason the application in that form would be very quickly forbidden. The question of efficiency would cut no figure there at all.

MR. SACHS:—Even though the Legislature—the present one is particularly good or likes to appear so—would appropriate enough money to bank up and wall up the canal and fix it so that the wash would not do any injury to the present mud bank, the efficiency differences are so enormous that by all means we want to adopt something to pull the boat instead of pushing it from behind. I think the propulsion of boats in narrow waterways is one that has been gone into quite exhaustively and found to be a problem a little different from the propulsion of a boat in an open water, and that problem increases very severely when you go to push that boat with a screw. I think Mr. Steinmetz himself will appreciate that fact. When you take a hauling motor of high efficiency, probably as Mr. Lamb will get his machine down to a single reduction, as he probably hopes to get his hauling sheave down to an efficiency of possibly 90 per cent. —with a motor of that kind, and if not that motor some other form of hauling motor, I think you can perhaps get twice the efficiency, if not more, than you can with a single screw propulsion for the same number of boats, the same speed and the same weight carried by each boat. I attempted to show that some time ago, and succeeded rather poorly.

MR. H. WARD LEONARD:—I also am quite interested in this question of the insulation, but from a different standpoint, as I have been doing some experimenting in that line with an insulating material, which it seems to me might have answered for this purpose. I have recently been making insulating joints in which the two parts of the insulating joints are held together with enamel, and it seems to me that it has the features which are described in this paper as necessary, as being non-absorbent of moisture and of high insulation, and having sufficient strength to stand the strains that were brought upon it mechanically.

MR. MAILLOUX:—I would like to ask Mr. Leonard if that material has elasticity. I think that is the principal physical qualification. It must have in addition to insulation a certain amount of elasticity.

MR. LEONARD:—I subjected the insulating joints I speak of to very severe rapping with a hammer, while they were holding the weights I thought they would meet in practice, and also subjected them to all the strain we could put upon them by means of a wrench. Of course it must be borne in mind that there is a very marked difference between enamel for such use, and anything in the shape of moulded glass. The strain which enamel will stand is enormously greater than what the mere moulded glass will stand, and most insulators that have been tried and found wanting, in the way of vitrous material, have been in a moulded form, and they have not the same strength.

MR. E. E. RIES:—I wish to say, since the discussion has drifted again to the question of insulation, that a number of years ago I had occasion to insulate the connecting rods of a very powerful steam locomotive, and after going all through this question in my endeavors to find an insulating material that would stand the strain of such heavy work, I met with exactly the same difficulties as have been recited here this evening. I finally adopted a new method of insulating, in which I used ordinary vulcanized fibre. I took a sheet of hard fibre about threesixteenths of an inch thick, bent it around into the form of a circle, and by means of hydraulic pressure forced the sheet of insulation between the brass bushing or collar which fitted over the driving crank of the locomotive wheel, and the opening or hole in the end of the connecting rod. The bushing, which had been made somewhat longer than usual and prepared with a conical or tapered end, was first turned down a trifle to reduce the outside diameter. The insulation was placed within the hole of the connecting rod and the brass bushing was then forced into place so as to leave a rigid wall of insulation between it and the rod, after which the projecting tapered end of the bushing was turned off so as to leave the bushing of the proper length. That insulation was by this process driven in so hard, under such enormous pressure, that it withstood the severe mechanical strain to which it was subjected perfectly, running day in and day out, and outlasted the ordinary brass bushings which are usually placed in those connecting rod ends. The insulation was also tested electrically at quite frequent intervals by means of an ordinary galvanometer and found very satisfactory, scarcely any deflection of the needle being noticeable. An incidental advantage of this construction was that the side rods of the locomotive ran much easier and were free from the mechanical vibration or "ring" which formerly characterized them when in operation.

Now, it occured to me that instead of attempting to patch up an insulating arm such as Mr. Lamb is using to support his traction cable by inserting a flat strip of insulation between the metal of the arm and a top plate which must necessarily be riveted or dovetailed or held on in some such way as that,—that if Mr. Lamb will follow the principle which I have adopted, and make his rest for the lower cable in the form of a sleeve, through which can be passed either a bolt capable of being screwed into the bracket, or the cylindrical end of the bracket itself, this bolt or bracket-end being forced into the sleeve containing the insulating sheet by hydraulic pressure, that he will get such a firm job that it cannot possibly be displaced, no matter what weight might be placed upon it. The traction cable would rest upon the upper surface of this insulated sleeve, which could be in the shape of a supporting saddle, and this sleeve or saddle, if necessary, could be connected directly with the feeder wires or with whatever circuit connections might be required to complete the installation.

MR. LAMB:—The trouble in that case would be, that, placed on the side of the saddle that the cable rests upon, it cannot be in any way covered and it would be exposed to water. The method that we are using is the simplest thing that could be devised. This cone-shaped pin (illustrating) is covered with half an inch of insulation, and this insulating material is pressed upon the pin at a pressure of 100,000 pounds to the square inch; it becomes almost like a solid piece of iron. Over the top of the pin the steel saddle fits. The cable rests on the top.

Mr. Ries:—That is exactly what I referred to—a plan of that sort. It is immaterial whether you have it in the shape of an umbrella head—

Mr. Lamb:—It has to be moulded, though. We cannot mould fibre. This fibre cannot be moulded; it has to be rolled.

Mr. Ries:—Of course such a substance would be preferable but at that time there was no such substance obtainable. Yet I obtained very excellent results I was under the impression that Mr. Lamb had not yet found a material that he could mould to the shape he desired and which at the same time would be sufficiently strong to answer the purpose.

The President:—As I understand, this method of insulation you employ is entirely successful?

Mr. Lamb:—Entirely so.

The President:—I think this discussion is entirely out of place. Mr. Lamb has already a successful insulation. Several members of the Institute have been instructing him in connection with a matter he has already solved, and apparently better than they have.

Mr. Lamb:—This insulation is non-hydrostatic. You can throw water on it and no two drops will stand together. They will all separate in small particles over the whole piece. It stood with a half inch thickness on one of those pins, a pressure on the top and a pressure on the bottom of 35,000 pounds without showing any indication whatever that it had had any pressure upon it, or any abrasion. We rolled heavy weights over it and it was in no way affected. I would not care to vouch for this statement, but a gentleman told me that a lot of this insulating material was put around a pebble and was thrown from one of the high buildings down at the end of Broadway, and it broke in two, the pebble and the material, just as though it were one kind of material.

Mr. A. E. Kennelly:—I would like to ask Mr. Lamb what is necessary to be done in the case of a break-down, if you want to put the motor on, or take the motor off at some point on the line. Is it necessary to start at the beginning of the line, or can you take up 14 feet slack at any point, or can you put 14 feet in the traction line at will?

Mr. Lamb:—You cannot take it off on the line. You have to pull the motor to the terminal to get it off. The terminal stations are situated at intervals along the line. At these places you can take the motor off. You can pull the motor along without unwinding the cable from the sheave or taking it off the cable.

Mr. Mailloux:—Does the motor ever run off the track?

Mr. Lamb:—If it could, I would have dropped with it before this. It is far more stable than a surface track would be, as the center of gravity of the motor is below the bearing rail, and deep flanges are on both sides of the wheels.

Mr. Sachs:—Mr. President, I do not think Mr. Lamb's motor ever takes any notion to run off the track, and I think that is rather one of the features that militates against it from the simple fact that it is mighty difficult to take it off the track. In taking off a motor from the track, in case it should be absolutely essential to do so, say for instance through accident at some intermediate points between terminals, it would be necessary to take off the pulling sheave. That pulling sheave encircles the elliptically grooved wheel say two or three times. That means so much slack cable. There must be some point where you will probably get enough slack cable to make it necessary to stop taking the motors off the line. But I should not think it would be essential at all to take any motors off the line on a system of that kind, for the simple reason that if a motor should break down, the motor going in the opposite direction would push that broken down motor back to the point it came from, and the next motor coming along would pull the waiting boat ahead. So I think there is no difficulty there.

Mr. Paul G. Burton:—I would like to ask Mr. Lamb a question about the wear of this cable in the sheaves. The method, as I understand it, is simply to make two or three bights right around the sheave in much the same manner as they are using throughout the city in these hoisting engines—what is commonly called a "niggerhead" in the trade. As far as I can discover, and I have had a little oversight of machinery—there is a good deal of wear even where there is simply a rolling friction. In this the cable enters on one side of an elliptical surface and goes out on the other. Consequently there must be a grinding all the time, and I would like to know what effect that has in the way of wear on the sleeve and on the cable. It seems to me it must be much more considerable than is claimed.

Mr. Lamb:—That depends on the difference in hardness which you would have between the cable and the face of this elliptically grooved sheave. You do not of course intend to build a sheave as hard as you would have the cable and expect the cable to last longer, because the face of this sheave is made so that you can remove the part that wears very easily and put another one on. It is inexpensive. But they have a very fair life and they are much larger than the winch-head that you referred to, and the bight of the rope is different. In one case you have a large circumference; in the other you have only 12 inches diameter. It in consequence would wear much harder. The actual distance of play is not very much, and the groove is very slight because it is paying in all the time just about evenly except when it is going around a curve. The two rollers in front and in the back, guide the rope and keep it in the right place on the sheave. On the other hand, when you have got a drum that is winding up a rope and it is elliptical in its groove, it pays off and winds down the cable a long distance on the drum. We only have in one case two coils of rope on, (three coils at the most), and they are guided, and there is very little play upon the sheaves.

Mr. Sachs:—I would like to have Mr. Lamb answer this question that I asked some time ago—that is, whether it is not a fact that one of the difficulties with this rope-hauling method is that the motor acts in a very fantastic and cranky fashion; that it takes sudden notions to stop and sudden notions to go ahead, and all that sort of thing. The motor may slacken its speed and the boat may be retarded slightly. That may mean an increase of speed or it may mean a stopping of the motor. In either case it must mean the attention of the attendant on the boat at once. I would like to know if there is not some system that Mr. Lamb has devised to obviate these objections, and if they are not real.

Mr. Lamb:—There would not be any reason for a motor stopping or not stopping except the loss of voltage. In the case of logging I never knew that to happen. On some of the Erie traction experimental trips it did happen. Our line was connected with a street trolley line and our voltage went from nothing to 500 volts. Sometimes the motor would stop, sometimes go slow, sometimes go fast. But there is nothing in the design of the motor that would give grounds for thinking it would go faster than at other times.

Mr. Sachs:—It was not a question of design of motor. It was a question of whether the regulating rope, the rope that you have connected from the operating controller and switch, unless you employ the rheostat for both functions, does not slacken as it certainly would. For instance, we will consider the boat and the motor propeller being propelled at a certain rate, and that suddenly you meet a curve in the line, or something of that sort, and a heavy load is put on the motor in addition to what is already carried. That would mean a slow-down, especially where you have not particularly excellent distribution. That slowing down must certainly mean that your rope is going to slacken and it certainly needs but very little slack in the rope to bring the rheostat back to the stop position;—at least so I should presume.

Mr. Lamb:—What would make the motor stop, would it not be the pull of the boat, the extra heavy pull?

Mr. Sachs:—I know—but your boat is moving forward. Its momentum is carrying it ahead at about the same speed as the motor previously pulled it. Now the motor gradually slacks up—it meets a curve—it has got to go up a steep incline, or there is some difficulty in the propelling machinery, and it slows down. That means that the boat is carried ahead and will be carried ahead for a few moments. But the motor is gradually slowing; that means that the rheostat is going back to where it started, and it means that the man has got to come forward and pull it.

Mr. Lamb:—That would not be the condition in practice. There is nothing on the line of the cableway that would stop that motor from its speed except the pull, and when the pull ceases, then you want your motor to stop, and that is the only time that the controlling rope is slack.

Mr. Sachs:—If you are going to build a motor to overcome any possible obstruction and any possible curve at the maximum load that the motor is going to pull, you are going to have a pretty big motor. The question of weight has to be considered in the construction of carriages.

The President:—I think it is rather late to take up that question of the relative efficiency of hauling and propulsion.

[Adjourned].

Associate Members elected by the Executive Committee, November 30th, 1897.

Name	Address.	Endorsed by.
Brackett, Byron B.	Instructor Electrical Engineering, Union College, Schenectady, N. Y.	H. A. Rowland. Louis Duncan. H. S. Hering.
Burroughs, Harris S.	1416 Pacific Street, Brooklyn, N. Y.	F. B. Crocker. M. I. Pupin. G. F. Sever.
De Lew, M. A.	Electrical and Mechanical Engineer, with Frank Lyman, 421 J Street, Sacramento, Cal.	T. A. W. Shock. Geo. P. Low. Louis Duncan.
Henderson, Alex.	Chief Inspector, Fire Dept. New York; residence, 321 West 118th Street, N. Y.	C. T. Hutchinson. Wm. A. Anthony. E. A. Leslie.
Mole, Harvey Edward	Ass't in Engineering Dept. J. G. White & Co., 29 B'way; residence, 320 West 58th St., New York City.	J. G. White. H. J. Ryan Ernest Merritt.
Peckham, W. C.	Prof. of Physics, Adelphi College, Brooklyn; residence, 406 Classon Ave., Brooklyn, N. Y.	Wm. S. Barstow. Samuel Sheldon. James Hamblet.
Spencer, Paul	Ass't Engineer, Stanley Electric & Mfg. Co, 39 Cortlandt Street, New York; residence, Montclair, N. J.	Wm. E. Geyer. Wm. Stanley. C. C. Chesney.
Venable, Wm. Mayo	Electrical Inspector, Cincinnati Underwriters' Association; residence, 3649 Vineyard Place, Cincinnati, O.	John A. Cabot. Thos. J. Creaghead H. S. Rodgers.
Willis, Edward J.	Supt. Richmond Traction Co., Richmond, Va.	E. W. Trafford. A. M. Schoen Herbert Lloyd.

Total 9.

A paper presented at the 120th Meeting of the American Institute of Electrical Engineers, New York, Dec. 15th, 1897, Vice-President Steinmetz in the Chair.

SPARKING, ITS CAUSE AND EFFECTS.

BY THORBURN REID.

Present theories in regard to the operation of commutation and the nature of sparking, show considerable progress beyond those of a few years ago. The most important step forward was taken when the reactance of the coil under commutation was recognized as the greatest obstacle to perfect commutation, and the duty of overcoming this reactance was assigned to the E. M. F. set up by the cutting of the lines from the field by the coil under commutation. It was also recognized that this must be limited by the available reversal E. M. F.

This was a long step forward, but it stopped just short of a complete explanation of the phenomena involved. This failure was due to an erroneous idea, which has fastened itself on the theory from the start, that injurious sparking was due to the current sparking across the gap between the brush and the receding segment, by reason either of incomplete reversal of the current, or of over-reversal.

I shall attempt to show in what follows, that sparking from either of these causes may be harmless, and that the real injury is done before the segment leaves the brush.

Taking first the simplest case of commutation, that of a coil of n turns with its ends connected to adjacent commutator segments, we may state the operation of perfect commutation thus:

First, consider a coil which is approaching a brush through which the current is entering the armature from the outside circuit. The brush covers the segment connected to one end of this coil, and half of the brush current is passing through the coil from segment 3 to segment 2 (Fig. 1), the other half from segment 3 to segment 4.

Second, consider this coil receding from the brush, which now covers segment 2, as shown in Fig. 5. Half of the brush current is now passing through the coil from segment 2 to segment 1, the other half passing through the next adjacent coil from segment 2 to segment 3. The current in the coil 3–2 now has the same value under the conditions shown in Fig. 5, as it had before in Fig. 1, but its direction of flow through the coil has been reversed. Between these two positions of the coil with reference to the brush, the whole operation of commutation has taken place, requiring generally but a very small fraction of a second.

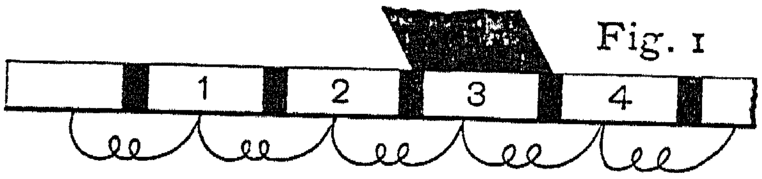

Fig. 1

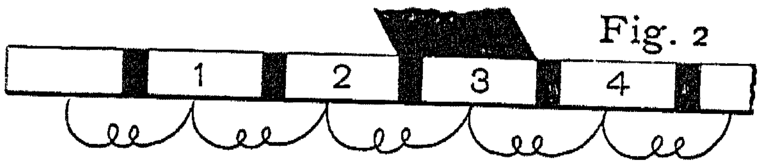

Fig. 2

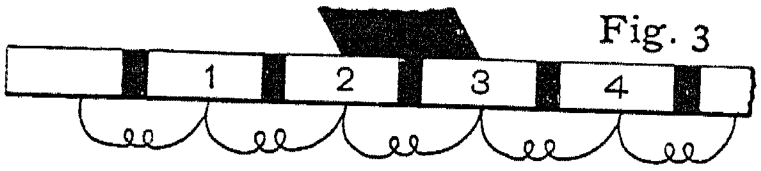

Fig. 3

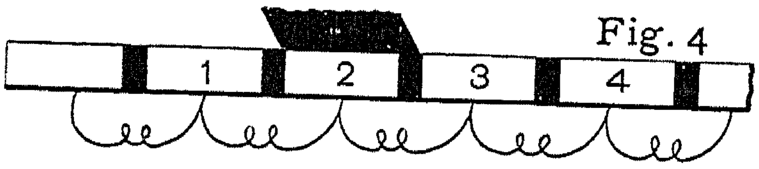

Fig. 4

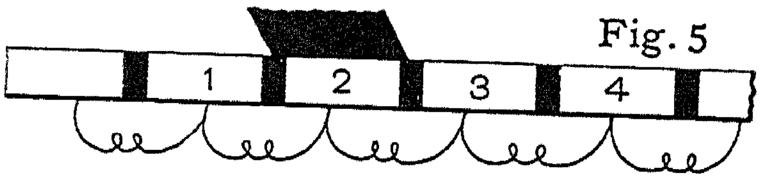

Fig. 5

Fig. 2 shows the first operation in commutation. The two ends of the coil are now connected through the brush, and the current passing around the left hand circuit of the armature has two possible paths, the one through segment 2, the other through segment 3. The amount of current which will flow from the brush direct to segment 2 depends on the difference of potential between the brush and segment 2, and on the resistance of contact area of segment 2.

Since the difference of potential of any two points in a circuit is the same through whatever path the current flows, this D. P. is equal to the algebraic sum of the potentials reckoned from the point of contact of the brush with segment 2 to the point of contact of the brush with segment 3, across this contact and through the coil to segment 2. The D. P. in the commutator segment need not be considered, as it is neglible. The D. P. in the brush itself is also negligible.

The D. P. across the area of contact of segment 3 varies directly with the current flowing across it, and inversely with the area of contact. The D. P. in the coil 3–2 depends on three factors, the CR drop in the coil, the counter E. M. F. of self-induction due to change in the value of the current, and the E. M. F. due to cutting the lines of force of the field. This last we will call "reversal E."

The CR drop varies with the current flowing in the coil. The counter E. M. F. or inductance drop varies with the rate of change of the current in the coil. Reversal E varies with the rate of cutting of the field lines.

The CR drop at the contact area and the CR drop in the coil both oppose the current, and the inductance drop aids it as long as the current is decreasing. The reversal E may act in either direction, but is usually opposed to the inductance E. Therefore the D. P. between the brush and segment 2 equals the CR between the brush and segment 3 plus the CR in the coil 3–2 minus the inductance drop in the coil, plus reversal E. It is seen that, as the brush moves over from the position of Fig. 2 to that of Fig. 3, the area of contact of segment 2 increases, while that of segment 3 decreases. Thus the resistance of the current path from the brush to segment 3 and through the coil to segment 2 is continually increasing, while the resistance from the brush to segment 2 direct is decreasing. Therefore the CR drop across the contact area of segment 3 will increase or decrease according as the contact area or current decreases more rapidly.

Thus throughout the period of commutation there is an increasing opposition to the passage of the current through the segment 3, and an increasing facility for its passage through segment 2 due merely to the changes of the areas of contact of the brush with the two segments, and to the consequent changes of resistance.

For perfect commutation which is the case we are considering at present, the impedance of the coil E should always be equal and opposite to the reversal E as will appear later.

The next period in commutation is that during which the current in the coil is increasing to its final value after having passed through zero.

When the current in the coil is zero, one-half of the brush current is passing through each of the two segments under the brush on the proper assumption that the current divides equally between the two halves of the armature. The CR drop at the contact surfaces of the two segments will then be inversely proportional to the area of the contact surfaces, and the difference between the impedance E and the reversal E will then, as before, be equal and opposite to the difference between the two CR drops at the contact surfaces. It should be noted here, that, although the current in the coil is zero, its rate of change may be considerable, and thus cause considerable inductance E.

While the current in the coil is increasing, the inductance E is in opposition to the current, while the reversal E is in the same direction with the current. Thus while in the first period of commutation, the inductance E prevented the decrease of the current, in this period it prevents its increase. The reversal E on the other hand aids the decrease of the current in the first period, as well as its increase in the second. The increase of the contact surface of segment two, and the decrease of that of segment 3 still continue to aid the flow of the current from segment 2 through the coil to segment 3, so that the effect of all these varying E. M. F.'s is just the same throughout this period as throughout the first period, but the resistance of the coil itself, which in the first period aided the decrease of the current, in this period opposes its increase.

Finally, just as segment 3 leaves the brush (Figure 4) the current in the coil becomes equal to one-half the brush current, and no current passes through from the brush to segment 3, and the segment leaves the brush without any difference of potential between it and the brush.

Now consider how the current should vary during the period of commutation, so that the energy of commutation will be developed equally over every part of the contact surface, and so that the amount of energy developed shall be a minimum.

First consider the variation of the current which will satisfy the first of these conditions. This condition will be fulfilled if the current density in every section remains constant as long as the area of contact is changing; for every part of the segment remains in contact with the brush for the same length of time, that is, the time required for that part to pass from the heel to the toe of the brush. Therefore, since every part is receiving energy at the same rate and for the same length of time, the energy developed in each part is equal. While the whole segment is covered, any change in the current density will affect every section equally, so that the current may vary in any way during that period, without causing unequal distribution of energy.

Consider how the current should change so as to develop the least energy. That is, how the current must be distributed between the contact surfaces of the segments so as to develop the least possible amount of energy.

Let R_1 and R_2 be the resistance of the two segments, and C_1 and C_2 the corresponding currents, C being the total current flowing. Then we have for the rate at which energy is being developed at any period.

$$W = C_1^2 . R_1 + (C - C_1)^2 R_2 \qquad (1)$$

Differentiating and equating to zero, we have

$$C_1 = \frac{R_2}{R_1 + R_2} C \qquad (2)$$

To determine whether this gives a maximum or minimum value, substitute in equation (1) for C_1 the values $C = 0$ and $C_1 = C$ and we get for $C_1 = 0$, $W = C^2 R_2$ and for $C_1 = C$, $W = C^2 R$. Both these values are higher than that obtained by substituting from equation (2) in equation (1), namely :

$$W = \frac{R_1 R_2}{R_1 + R_2} C^2$$

Therefore that value of C_1 makes W a minimum.

This means that for each position of the brush, the energy developed at the contact surface will be a minimum when the current divides between the segments under the brush in the ratio of their areas of contact. It is seen that under these conditions, the current density remains constant, and that therefore the requirements of equal distribution of energy are also fulfilled.

Perfect commutation may now be defined as a complete reversal of the current in the coil under commutation in such a manner that the portions of the current flowing through the two segments to which the ends of the coil are connected, shall be proportional to the respective contact areas of the segments.

It was shown above that $C_2 R_2 = C_1 R_1 + CR$ drop in the coil plus the inductance E in the coil plus the reversal E. If therefore the sum of the CR drop of the coil plus its inductance E were always equal and opposite to the reversal E, C_1R_1 would be equal to C_2R_2, which is the condition for perfect commutation as defined above.

Following are some of the various ways in which imperfect commutation may occur, and the manner in which this imperfect commutation causes injury to the commutator.

First. Suppose that the current flowing across the contact surface of the receding segment does not decrease as rapidly as the contact surface of that segment decreases. The current density then increases and is a maximum at the last part of the segment that touches the brush. More energy is thus concentrated at that point than at any other, and owing to the fact that time is required to conduct that energy to other parts of the segment, that part will be raised to the highest temperature. This temperature may be high enough to melt, or even volatilize the copper of the segment, therefore when the brush leaves the segment, the current continues to flow through the film of melted copper, volatilizes it and draws an arc. This arc constitutes the injurious or "vicious" spark. The removal of the volatilized copper from the receding edge gradually wears that edge away. Reduction of the contact surface thus continually increases the current density, and the arc is formed at an earlier stage of the commutation when the current to be broken is greater, and thus the spark increases in viciousness until the commutator has to be turned down before the machine will run at all.

Again the energy developed at the receding edge of the segment may not be sufficient to melt the copper. In this case the current to be broken when the segment leaves the brush will jump across from the brush to the segment. This spark has no deleterious effect, since most of its energy is developed in the space between the segment and the receding brush, instead of being concentrated at the edge of the receding segment. This spark is of the same bluish color as that of the Ruhmkorff coil, by which it may be distinguished from the injurious spark, which is yellow.

Second. Suppose that the current flowing across the contact area of the entering segment increases more rapidly than the contact surface increases. The current density in that part of the segment then increases, and more energy is concentrated at this point than at other parts of the segment and it will accordingly be raised to a higher temperature. If this temperature is not high enough to melt the copper, no harm results and there is no spark, since the contact is not broken at that point. If, however, the temperature produced is high enough to melt the copper, the melted copper may be carried along by the brush, and the entering edge of the segment is thus gradually eaten away. This will not show by any sparking immediately, but it will eventually cause a spark to appear in the following manner: The eating away of the entering edge of the segment gradually reduces the area of the entering segment and thus increases the resistance of that segment. This delays the decrease of current in the receding segment, and the current density in both segments increases until the temperature gets high enough to produce a spark as described in the first case of imperfect commutation. Another incidental injury that may occur is the deposition of the melted copper at the back of the segment, thus raising the surface of the segment at that point, and this, together with the depression of the surface at the front of the segment, would cause the brush to jump and chatter, which of itself would cause deleterious sparking.

This would explain the cases where a machine runs perfectly sparkless when first set up, but after a time commences to spark, the spark increasing in intensity and deleterious effect and disappearing when the commutator surface has been turned up, only to reappear after sufficient time has elapsed. The wearing away of the front edge of the segment is hardly likely to be noticed, since no injury would be looked for until the spark appeared, and then the cutting of the back edge would be much more prominent, because that, being produced by an arc, would have a roughened appearance, while the surface of the front edge would be left smooth by the rubbing off of the melted copper.

Third. The reversal E may be large enough, not only to reverse the current in the coil under commutation, but even to increase it beyond the value of half the brush current. In this case the extra current would flow through both segment surfaces, but owing to the fact that this current would be increasing while the receding segment was reducing its contact area, that segment would get hottest, and as soon as it reached the melting point an arc would be drawn and destructive sparking would ensue.

The problem that the designer of the modern machine has before him is to design a machine that will run from no load to 25 per cent. above full load without sparking, and without movement of the brushes.

In the case of machines intended for lighting, the condition of no shifting of the brushes is not generally required, but most of our modern lighting machines are made to fill that requirement.

The current to be reversed therefore varies from the exciting current of the machine up to 25 per cent. above its full load current. The inductance E and the CR drop in the coil also vary in this proportion, and for perfect commutation through all these varying loads it would be necessary for the reversal E also to vary in the same proportion. As a matter of fact, the reversal E does not vary in anything like the same proportion, and may even decrease with increase of load, on account of distortion of the flux coming from the field by the armature ampere-turns.

Perfect commutation for any particular position of the brushes can therefore only take place at one value of the load. At heavier loads than this critical one the current is not completely reversed before the segment leaves the brush and at lighter loads it is more than reversed. This problem may be stated a little more precisely in the following manner:—

Assume that the brushes are set as far back as is consistent with sparkless running at the maximum load at which the machine is required to run sparklessly. This means that the reversal E is just equal to the coil impedance E at that point. Now let the load be removed gradually. The impedance E of the coil under commutation is reduced, while the reversal E remains practically constant. The tendency is therefore for the current to be more than reversed, and this tendency increases as the load is reduced, until finally, when the load has been removed entirely, there is no current to reverse, and the reversal E simply tends to produce a current in the coil under commutation. The production of this current is now opposed by the inductance and resistance of the coil, and by the resistance of the brush contact surfaces, the contact surfaces of the two segments being in series as regards this current. If the impedance of the coil is low as compared with this contact resistance, the reversal E would be small compared with the CR drop across the contact surfaces at full load current. Therefore the current produced by the reversal E would be small as compared with the full load current.

We may also note here, that, whereas the variation of the contact resistances aids the reversal of the current, as soon as this current becomes greater than that which flows through the armature, the excess current must pass across the contact areas of both the segments under the brush. The resistances of these two surfaces are then placed in series as regards this current, and the lowest possible resistance that these could have, would be reached when the brush covers an equal surface on each segment, making the contact resistance in the path of this current equal to twice the resistance of the contact surface of either segment at that time. The resistance of this path then starts at infinity, decreases to this minimum and goes back to infinity again.

Now examine more closely the order of events in commutation at no load. The resistance of the coil circuit first starts at infinity and rapidly decreases, while the reversal E starts at a minimum and more slowly increases. As soon as a current commences to flow, inductance E enters the problem. If there were no contact resistance, the current would reach its normal full load value at about the middle of the commutation period. This of course assumes that the reversal E is of such a magnitude as to reverse the current at full load without the aid of the varying contact resistances. In fact the reversal E does a very small part of the reversing at full load when the inductance is small compared with the contact resistances. The current at the middle of the commutation period would therefore be much smaller than the normal full load current, even if there were no contact resistance to limit it. Now introducing this contact resistance, which starts at infinity and decreases to a minimum, which may be several times greater than the impedance of the coil, the current must be reduced at least in the proportion of the impedance to this minimum resistance. During the rest of that period the resistance is increasing till at the end it has reached infinity again. The current, already very small, is rapidly cut down till it is too small to produce a visible spark at the break, and the commutator has not been heated up enough at any point to produce arcing.

The same principles hold in the case of machines whose brushes must be shifted, the range of sparkless commutation only being less.

There have been some machines, however, which would not run sparklessly for any position of the brushes. This is readily explained on the hypothesis of too high an impedance, for in that case the variation of the current during commutation will be mainly governed by the impedance and reversal E, instead of by the variation of the contact resistances, so that even if complete reversal is exactly attained, the current density at other parts of the commutation period does not remain constant, with the result that the total energy of commutation is increased. A large part of this energy is concentrated at the beginning and end of the commutation period, thus producing heating at the edges of the segments, with its corresponding melting of the copper and arcing.

These considerations indicate two ways by which sparkless commutation may be assured. First by increasing the brush contact resistance, and second by decreasing the impedance of the coil under commutation.

The limitation of the second of these conditions is merely one of economical design, lowering of the inductance below a certain point increasing the cost of the machine.

The limitation of the first condition is that of rise of temperature of the commutator. It has been shown that for perfect commutation the current density is constant and uniform throughout the whole period of commutation. Its value is found by dividing the total brush current by the contact area of the segments under a brush. This varies inversely with the brush contact area, and the energy developed therefore varies in the same proportion. The amount of commutator metal to be heated, as well as the radiating surface, also varies inversely with the current density, so that the rise of temperature probably varies nearly as the square of the current density, provided the commutation be practically perfect.

The increasing use of the carbon brush in place of the copper brush is thus explained by the fact that the contact resistance of carbon on copper per square inch is much greater than that of copper on copper. Increased resistance is obtained with the copper brush by reducing its contact area, but this also reduces the metal to be heated in the commutator, as well as its radiating surface, so that the same amount of commutating energy will result in a much greater rise of temperature.

By taking these facts into consideration, however, and properly proportioning the contact areas and inductance, commutating machines may be designed to run as cool with copper brushes as with carbon wherever this may be desirable.

The reasoning so far has been based on the assumption of but one coil being commutated at a time. This assumption will only be true when the brush thickness is equal to, or less than the width of one segment, plus twice the thickness of the insulation between segments. In practice, brushes are often made to cover a segment and a half, sometimes two segments or even more than this without deleterious sparking. This means that the current in two or more coils is being commutated at the same time.

At first sight this appears to be an advantage, since it enables us to get the same current density with less length of commutator, but the time of commutation is increased, so that while the rate of development of energy is not changed, the total amount of energy developed will vary with the time of commutation, and in addition to this, the amount of metal to be heated and the radiating surface are both decreased, so that in this respect the change is rather a disadvantage than an advantage. Another important advantage is gained, however, in that the increase in the length of the commutation period decreases the reactance of the coil by decreasing its frequency of commutation, so that the ratio of impedance to contact resistance is decreased, thus tending towards more perfect commutation. This advantage is again limited by the fact that the mutual inductance of two coils commutating at the same time increases the reactance of both.

To sum up, the deleterious effects of sparking are due to excessive local heating of the commutator contact surface, causing the copper to melt, and an arc to be drawn, the segments being thus disintegrated.

The causes of deleterious sparking are, either too great a departure from perfect commutation, or too high a current density.

Perfect commutation can only be practically secured by making the impedance of the coil negligible as compared with the contact resistance.

A comparison of the sparking constants of a large number of machines was made before this theory of commutation was evolved.

It has been found to explain many cases of sparking, which had before been unexplained.

It has been found difficult to determine definite safe working constants, on account of the small number of tests that have been made to determine accurately the inductance of the coil under commutation and the effect on each other of two or more coils commutating at the same time.

DISCUSSION.

THE CHAIRMAN (Mr. Steinmetz):—We have listened to a very interesting paper, and I believe Mr. Reid deserves our thanks very fully for the masterly manner in which he has dealt with this very difficult problem; the most difficult problem, I believe, in the design of direct current constant potential machinery, which electricians have had to meet in the development of the last ten or fifteen years. The discussion is now in order and I call on Mr. Dunn to open it.

MR. GANO S. DUNN:—I agree with the Chairman as regards the importance of this paper. It was in reference to this feature of dynamo design that Lord Kelvin observed that if as much time had been put upon direct, as has been put upon alternating current apparatus, the direct current would have been as far ahead to-day. In the comments I shall make on Mr. Reid's paper, I only desire to bring out further information so that the subject may be advanced at the end of our discussion.

Mr. Reid states: "The amount of current which will flow from "the brush direct to segment 2 depends on the difference of po-"tential between the brush and segment 2, and on the resistance "of the contact area of segment 2." Later he states that the resistance of the brush is negligible. I think that he is in error,— First, that the resistance of the contact area of the brush is what controls the distribution of current from one segment to the other, and second, that the resistance of the brush is negligible. My work has been to show that the latter is a large and controlling factor in the problem and affects commutation more than does the contact resistance of the brush with the commutator. In proof of this, I will cite the fact that a carbon brush which will stop the sparking on a 25 H. P. motor wound for 110 volts, will not stop the sparking for the same motor when wound for 500 volts. But a graphite brush or carbon brush of very much higher resistance will stop it. In the same connection, where a copper brush will not stop sparking on a 110-volt dynamo, a copper gauze brush will—I believe because of the higher resistance of the gauze and not because of the diminished contact area resulting in a higher contact resistance. I believe that the resistance of the brushes is as much a function of the design of dynamos as the resistance of the armature winding, and that the resistance of the brushes should increase for a machine of given size and output with the square of the voltage for which it is wound. I have been able to prove this law partially. It is impossible to get carbon of all grades of resistance, but graphite may be obtained of any resistance above a certain point to 200 ohms to the inch of length, and I have had made, brushes of varying resistance and found that the low resistance brushes will commutate for low voltages and the higher resistance brushes will commutate for higher voltages, and so on, and while I have not been able to prove the law as one of squares, yet it seems to go up in about that proportion. I would also call attention in this connection to the Wirt brushes which are effective in stopping sparking. They depend on the higher resistance of the leaves of the brush near the outside, to compel the reversal of the coil when the segment is near the brush tips. Now if it was contact resistance, the contact resistance of the external leaves would not differ sufficiently from that of the internal leaves to account for the reversal, and Mr. Wirt finds that by changing the specific resistance of the external leaves of his brush he completely alters the commutating conditions.

The drop of potential in the brush itself is negligible as compared with the circuit voltage, but is not negligible as compared with the reactance of the coil under commutation.

Further on Mr. Reid states: "The D. P. in the coil 3–2 depends on "three factors, the CR drop in the coil, the counter-E. M. F. of self-in- "duction due to change in the value of the current and the E M. F.

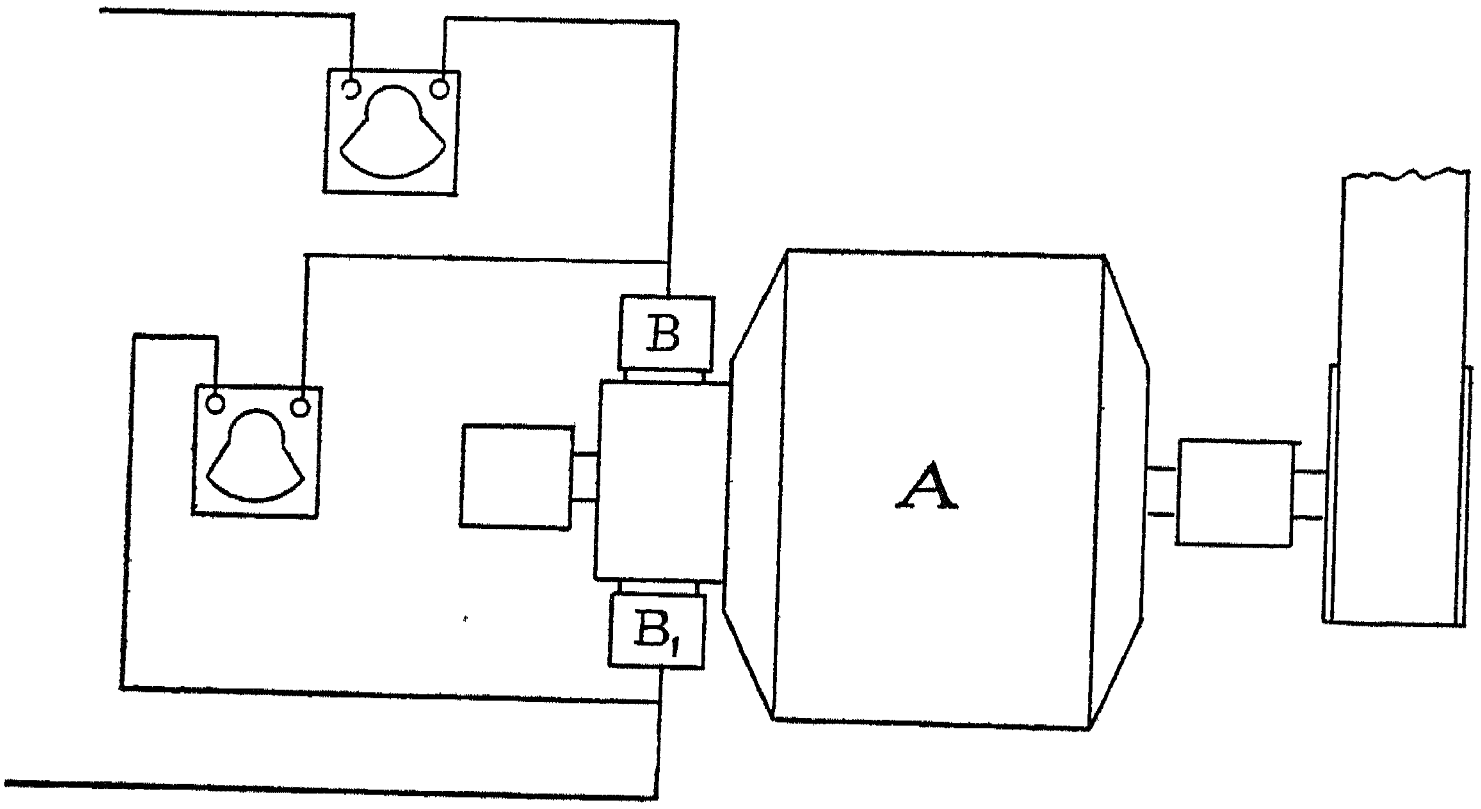

FIG. 1.

"due to cutting the lines of force of the field." And "the CR "drop varies with the current flowing in the coil." And later he also states that the CR drop is an appreciable part of the reactance. With slotted armatures, with which I have had mostly to deal, the CR drop may be neglected, for it forms but about ten per cent. of the total reactance. This brings up the question of how we can divide the reactance into its factors of inductive and ohmic terms, and for that purpose I devised a method some five years ago which I published in a lecture before the New York Electrical Society and which I found to work experimentally very well. It has served my purposes well until recent date when I have computed the inductances of slots instead of determining them empirically. This method of determining the reaction of an armature I will show on the board. Let A (Fig. 1) be an armature of which we wish to measure the reactance. Fix it in bearings away from the influence of any field and be prepared to drive it with a pulley at its normal speed. Then take its normal full load current from some external source, and pass it through the armature. Now attach a voltmeter from B to B′ and note the drop in the voltmeter. This drop will represent the ohmic drop of the conductors in the armature, plus the drop due to the contact resistance. Now spin the armature and note the increase of the drop across it. There will be an increase, because as the current enters the armature, it divides down both sides equally and goes through coils on each side of the brush, which have considerable self-induction, and as the armature revolves each coil has to be reversed which its self-induction opposes. Therefore the current passing through the armature being opposed, the voltmeter will rise. Now subtract from the voltage when the armature is running, the voltage when it is at rest, make allowance for the contact resistance, which may be determined, and for resistance of the brush, and you have directly in volts the reactance of the armature, and you have it in the way that you most desire to know it. This method measures the reactance at the coil's own high frequency and not at some lower one.

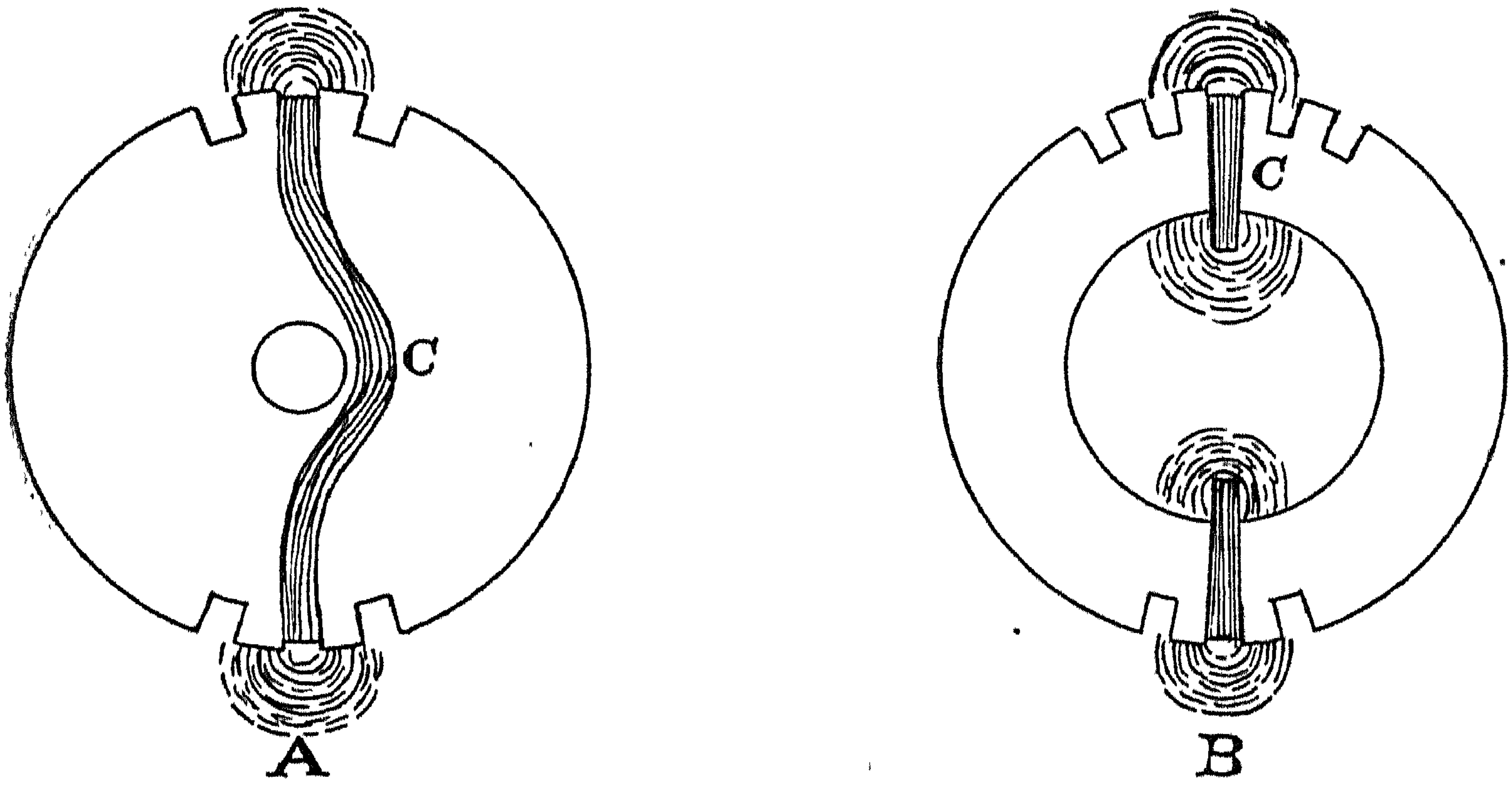

FIG. 2.

To design dynamos from this empirical method, it is only necessary to take an armature whose reactance you have measured, as a standard of comparison. Measure the length and the depth and the width of its slot, which indicate the permeance and make the dimensions of slots of the new armature in proper ratio to the old. If you want an armature with half reactance make the slot twice as wide, or half as long, or take out some of the turns or use half the frequency. With these empirical methods I have arrived at very accurate and good results. Recently this inductance has been computed, taking into consideration all the factors, and it is remarkable how closely it agrees with the results measured as above. It comes out a little higher, and this I believe is due, as Mr. Steinmetz suggested at the General Meeting at Greenacre, to the fact that the frequency of reversal in the armature is so rapid that the self-induction conditions are altered. The frequency in the coil of a direct current armature varies from about 500 to 1500 a second, which is much higher than ordinary frequencies. Now either by computation or by this measurement you can figure out, when you are designing a machine, just how many volts reactance you will have, and can proportion the resistance and area of your brushes accordingly. I have done this a great many times and the results have been what were predicted.

Further on Mr. Reid says: "This arc constitutes the injurious "or vicious spark." I would note in this connection that there is a certain condition of sparking which rapidly develops the vicious spark, and I think it is due to the fact that the throwing of this volume of current coming down the brush (B Fig. 3) over into the toe, greatly reduces the resistance of the toe on account of the property of carbon, of reducing its resistance when hot, and this resistance once reduced, the brush is deprived of its ability to reverse the coil in a still greater measure than before.

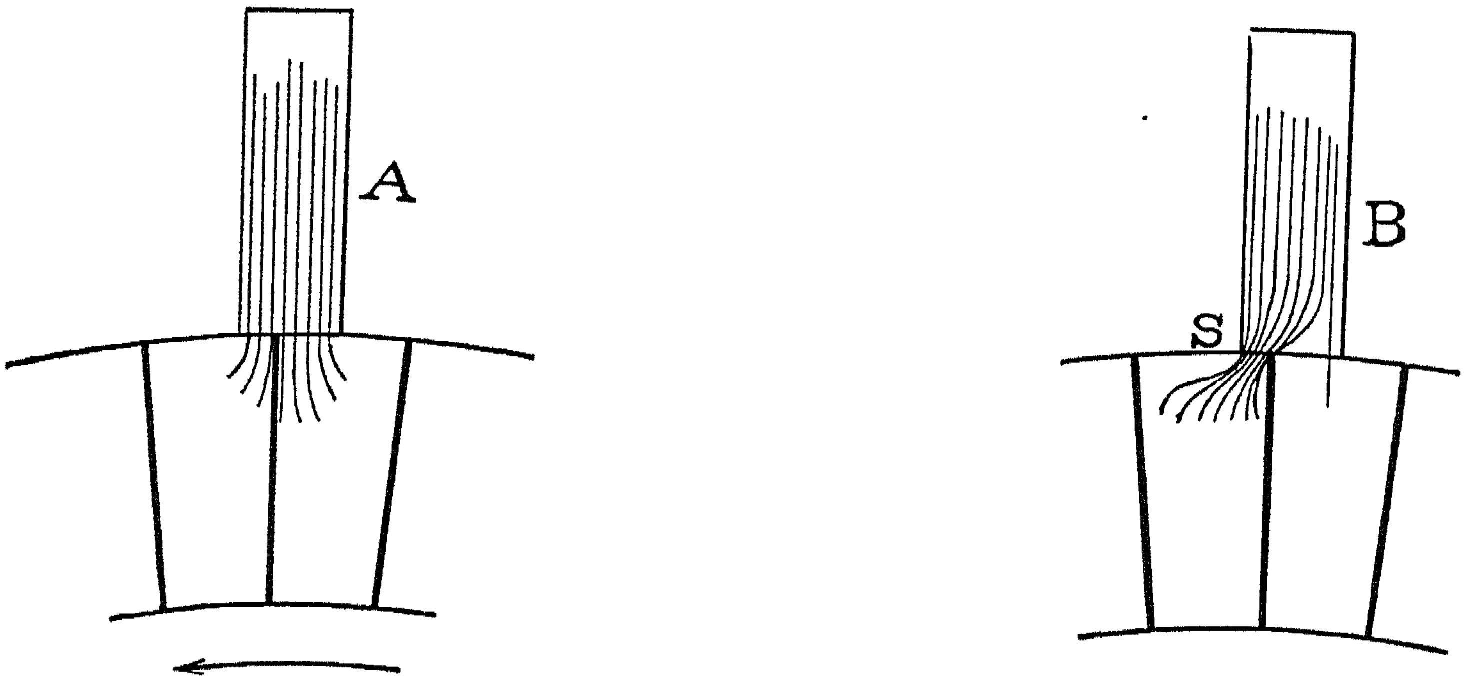

FIG. 3.

I have found considerable difference in the inductance between rings and drums. Why, I have not yet been able to prove, but I presume it is because a ring exposes considerably more area than a drum, and has in addition internal surfaces. If, in Fig. 2, B is a ring armature, and C is the coil, the path of the lines is across the slot, and also up through the air. But there are also paths as shown inside the ring; whereas in a drum armature as A, where the coil is wound straight across, the path can be only from one-half of the peripheral surface to the other.

With regard to terms, Mr. Steinmetz in some of his earlier works on this problem has used the terms "natural commutation" and "forced commutation." By natural commutation he meant such commutation as I have shown, where the brushes did the reversing, and by forced commutation he meant commutation which is done magnetically by the pole-tip. I think those terms are not as appropriate as they should be, and propose the terms "resistance commutation" for the one in which the brush does the work, and "magnetic commutation" for the one in which the pole does the work.

Towards the end of the paper, Mr. Reid states: "These considerations indicate two ways by which sparkless commutation may "be assured; first, by increasing the brush contact resistance, "and second, by decreasing the impedance of the coil under commutation." If we could increase the brush contact resistance indefinitely we should have a solution of all our troubles. It would only be necessary to build very large commutators, and put much clay or foreign matter into graphite to get it of very high resistance to commutate a 20,000-volt dynamo if you please. But when a brush gets up to such an exceedingly high resistance, the resistance is comparable to the resistance of the hot air at the edge of the brush where the spark occurs. At s, Fig. 3, the resistance of the hot air may be lower than the resistance of the brush, and when you have reached this point it does not pay to increase the resistance of the brush. By decreasing the impedance of the coil under commutation we have the only solution that leads us to hope for perfect commutation. Mr. Reid states that the limitation of this condition is merely one of economical design lowering the inductance below a certain point, and increasing the cost of the machine. That is very true. But not only does it increase the cost of the machine but it decreases its efficiency and decreases at the very point at which we wish a very high efficiency—namely, at light loads; and the machine that is sparkless from a low reactance in its coil, has to have in addition to having its slots of proper design, a large flux, and a large flux while not antagonistic to economy at full load, is very antagonistic to efficiency at light loads. Mr. Reid states that the limitation of the first condition is that of the rise of temperature of the commutator. Commutators in the future will be designed with a certain number of watts per square inch of radiating surface, the same as armatures and field magnets have been designed in the past.

There is an important point, however, that ought to be brought up in this connection. A great many engineers specify a current density in carbon brushes of 30 amperes per square inch. This rule is good as far as the conducting capacity of the brush is concerned; but from a scientific point of view is of no use whatever as affecting commutation. Fig. 3 shows a commutator, and its brush A under conditions of no self-induction, and B with self-induction present. If you think to design for 30 amperes per square inch density, and have a high reactance in the armature coil, what is going to happen? What Mr. Reid calls the "centre of commutation" will move from the middle of the brush over into the toe towards s, and the higher reactance the further into that toe the centre of commutation will move, resulting in having almost all of your current going down through a small region near the toe, and practically none going through the rest. You think you have 30 amperes per square inch when you may have 200. It is easy to have a lesser actual density than this in a brush of 60 amperes per square inch apparent density by due attention to the inductance, and it is at this latter point specifications should aim, and not at the density for simple conduction The conduction density is not one to go by, although it is very greatly used and insisted upon. The way to figure the watts per square inch a commutator will have to emit, is to take the reactive volts as measured in the method I have suggested, or as computed—and multiply by the current, and then after adding frictions and ohmic losses put these watts into the surface of the commutator. This is definite, and does not depend upon the cross-section of the brush. I will state that the reactive volts in a 25-horse-power 230-volt armature are about two volts, and the ohmic drop in the same armature about five volts.

With regard to the number of sections that a brush should cover, I disagree with Mr. Reid about the effects of covering more than one segment. I have made the experiment, and find that between a brush covering say two segments—and the same brush when you have filed away the edge so that it covers only one segment, the inductive volts differ for 100 per cent. increase of surface only by about 15 per cent. This leads to a point which is not generally known, of the effect on its sparking of the number of segments in an armature. It is thought that to increase the number of segments greatly diminishes the sparking. This is true only as far as relates to the volts per bar. In a 500-volt machine if you get much over 20 or 25 volts per bar between the brushes you will have ring fire and flashing. That kind of sparking is affected by the number of segments. But if you have an armature with 40 segments, and it sparks from inductive causes you will not help it by giving it 80. The reason is that the sparking is a function of the conformation of the slots and armature generally, and is not affected by the number of subdivisions. This comes out in the point about the number of segments the brush covers. It does seem reasonable that if a brush covers two segments of a commutator instead of one, that the time allowed for reversal and the number of lines that will be cut by the coil under the pole would be twice as much, and therefore that the reversal ought to take place much earlier. But that is no more true than the fact that if you short-circuit a hundred cells of gravity battery you will get no more current than if you short-circuit but one. Why is it that the reactive volts measured as I have described, do not vary appreciably when you double or halve the contact area of the brush? I think it is for the reason that the contact area of the brush is not a principal factor, but that the reactance of the armature driving the volume of current over into the toe, determines how much of the brush shall be used, and therefore it is immaterial whether we have the whole or a part of the brush bearing on the commutator. The criterion that I have established for armatures, is the number of volts that the reactance figures out or measures for a given circuit voltage. On 230-volt machines with ordinary carbon brushes, commutation will take place sufficiently well for heavy duty with a reactive voltage of two volts. If the machine is to be used for intermittent work, and has to have its brushes in the middle, this voltage may be increased to five volts. For 500-volt machines where you can use graphite brushes and have them of as high resistance as you please, the voltage may be increased to double these values. The design of the dynamo ought to be decided for reactive voltage of the coils, as it is decided for ohmic resistance of the armature, for electro-motive force and for other features.

One more point, and that is Mr. Reid speaks of perfect commutation as being obtained by the resistance method. I have pointed out the limitations of resistance commutation. I think that if we ever design very high voltage direct current dynamos we shall do it by means of magnetic commutation. The objection to magnetic commutation at present is this: The fringe at a pole shoe is practically constant, or worse, it grows smaller as the load grows larger. Your commutation electro-motive force therefore is fixed, while the electro-motive force of self-induction in your coil varies with the current the coil is carrying. It is zero at no load and high at full load. What you have to do is to set the brush for average conditions and have it hold the commutation back at light loads and help it at heavy loads. If we have a means of magnetic commutation, *e. g.*, a proportioning of the fringe so it varies in strength directly as the load, why can't we depend on magnetic commutation for all loads and for very high voltages? Such for instance would be a supplementary magnet with a coil around it in series with the current going through the motor. As this current increased, the magnet would strengthen and give more magnetic fringe for magnetic commutation directly in proportion to the need of the coil. I have been working on a method of this kind to be applicable to high voltage machines, and while in the course of every-day life we are very busy and do not have a chance to develop all our ideas I hope some day to see high voltage generators designed on this principle.

THE CHAIRMAN:—(Mr. Steinmetz). Gentlemen, we can congratulate ourselves on having had Mr. Reid's masterly paper supplemented by the very interesting and valuable discussion of Mr. Dunn.

There is one point in Mr. Reid's paper towards the end, in the discussion of the desirable width of brushes, which may be slightly modified by taking into view another quantity—the friction of the brush on the commutator, which heats the commutator just as much as the $c^2 R$ does. This friction loss varies naturally with the width of the brush. So taking this into view his conclusion should be slightly modified.

I may answer Mr. Dunn regarding his desire that commutators should be designed by considering the watts per square inch, that for about two years past all the commutators of the company with which I am connected are designed this way, by calculating the energy lost of the commutator by the friction of the brush and the $c^2 R$ loss of the contact resistance, and figuring thence the necessary area of the commutator to dissipate this amount of energy. As pointed out by Mr. Dunn, the use of very low impedance is inefficient, due to the very high flux, giving high light load loss. In the commutator you have a similar feature. The $c^2 R$ loss at the brush contact varies with the load, but the friction loss is constant, and thus a light load loss. The lower you take the current density of the brush, the lower also is the light load efficiency of the brush. It is hardly appreciated by most people what an enormous amount of energy is wasted at the commutator of the low voltage machines In a 50-volt machine this loss is very frequently five per cent. and more, of the output, and obviously the most economical design is very near that, where the variable loss is equal to the constant loss, or the friction loss, at the load at which the machine is desired to operate mostly. This means that the best current density at the brush contact, is not 30 amperes and not 40 amperes, but depends on the peripheral speed of the commutator. For high-speed commutators, a higher current density is usually preferable, in low speed commutators a lower current density. All this has to be taken into account now in designing commutators of direct current machines.

I do not agree with Mr. Dunn that the resistance of the brush proper is the main factor, but I agree rather with Mr. Reid that it is the contact resistance. It is undoubtedly true that special brushes can be made with high internal resistance, but with ordinary carbon brushes the internal resistance of the brush is negligible, compared with the contact resistance.

The experience of Mr. Dunn and this apparent law of voltage is very easily explained thus: If we rewind a machine, say for twice the voltage, we get twice as many turns on the armature, or per commutator segment, of half the cross-section, that is four times the resistance, and four times the reactance. That means we have to have four times the resistance in the brush to get e same relative proportion of reactance, etc., as commutation stants. If a machine sparks, for instance, as a 550-volt hine more than a 110-volt machine, it is due to the fact that, le the contact resistance is the same numerically, it is only -twenty-fifth relatively to the reactance in the 550-volt machine n the 110 volt-machine, and that I believe explains the feature. agree that resistance commutation is a very desirable name, better than natural commutation. But I do not agree with the word magnetic commutation, for the reason that the word magnetic commutation has a definite meaning already. It means the commutation of the magnetic circuit. There are quite a number of apparatus in commercial use now-a-days where commutation of the magnetic flux takes place, as magneto-potential regulators and such apparatus, where primary coils and secondary coils are stationary with regard to each other, and merely the direction of the magnetic flux is changed by moving a part of the magnetic circuit. Even the ordinary inductor alternator is really a kind of magneto-commutation machine. Thus I think to avoid confusion it is better to find another term expressing this phenomon.

MR. DUNN:—May I comment on your remark about the reactance? The reactance of a dynamo at double voltage would be four times the reactance of the other if the current were the same; but the current is only one half; therefore the reactive volts vary as a direct function of the circuit voltage and not as the square, and therefore the resistance of the brush requiring to go up as the square, does not follow the same law as the increase of the reactive volts.

THE CHAIRMAN:—Yes, it does; because the resistance volts decrease with the current. If the reactance volts increase only proportionately to the voltage, the resistance volts which enter the same circuit decrease with the current, that is, inversely proportional to the voltage. You either have to compare resistances and reactances, or resistance volts and reactance volts; in either case, you get proportionality to the square of the voltage.

This leads to another feature which I forgot in discussing the reactance volts. This reactance E. M. F. is really not a constant voltage. In your experiment the measured voltage really does not give you directly the reactance, because the reactance E. M. F. is not a steady voltage during commutation, nor is it an alternating voltage, as the term "frequency of commutation" implies. but it is a very complex exponential function Since the resistance varies with some kind of linear or even more complex law, the problem of commutation leads to a differential execution, which we cannot integrate any more; that is, I do not know whether it can be integrated; I tried once and did not succeed.

MR. DUNN:—I do not think after this that anybody will attempt to integrate that equation.

THE CHAIRMAN:—Is there any more discussion on this paper?

MR. REID:—I may be able to start this discussion again by speaking of some of the questions brought up by Mr. Dunn's remarks. To begin with the first thing, he speaks [illegible] the brush resistance itself being of more importance than the [illegible] contact resistance, and he says that he has measured this brush resistance in special cases and found that the brush resistance [illegible] being increased, has stopped sparking. The question that occurred to me was, whether the brush contact resistance wa [illegible] the same time. I have not tried it and do not know. I have only used one form of carbon brush, and I have never used the Wirt brush. In the case of the difference between the copper brush and the gauze brush, it struck me that the contact resistance of the gauze brush would be higher than the strip copper brush.

Then, in regard to the C R drop of the coil under commutation being negligible as compared with the reactance, I have found that in a good many cases, but not in all, and I think that Mr. Dunn's finding it so can be explained by some other points in his discussion. He says that he gets two volts reactance in a 35 horse-power motor. In no motor that I have dealt with have I got over half a volt reactance. So I imagine that he must get rid of his sparking by some other means than I have used, as two volts would chew my commutator up in very short order. In all that Mr. Dunn said, it impressed me that he was still clinging to the idea that the cause of injury in sparking was this jumping of the spark across the gap between the receding segment and the brush; I am not sure that I was right in that, but that was the impression I got from his remarks. Now the main point that I intended to bring out in this paper was the fact that the injury was done before the segment left the brush; that the spark was a mere indication of injury already done; that is, when the segment leaves the brush, the copper has already been melted; the current goes through this melted film of copper and volatilizes the copper which would have been taken away from the segment anyway.

In regard to the test for reactance, I agree with Mr. Steinmetz in that. We have a variation of contact resistance all the time, and various other quantities that would make it very difficult to say just what was measured by that test. I never heard of the test before, and would not be sure that it was not accurate, but at the first sight it appears to me to take in too many variables for us to be certain what we have when we get through.

Then, in the latter part of Mr. Dunn's discussion, he seemed to me to assume imperfect commutation. He speaks of the limits of resistance commutation. I do not see that he mentioned any such limit, and I do not see how there could be any as far as commutation was concerned. Of course, the resistance commutation, what I have called perfect commutation, might be very expensive. That is one limit. But otherwise, the more perfect the commutation, the better the machine.

In regard to magnetic commutation which he recommends, and which he says might be done by means of an extra pole. So it might. People have been trying to do it for a long time, but I haven't found that anybody has succeeded very well as yet. We have had various shapes of poles and various other devices for performing what he calls magnetic commutation. But I have yet to see any machine regularly manufactured, with any simple form of magnetic commutation. There are one or two, or one at any rate, the Ryan dynamo, which is very complicated. There is no other that I know of that has been regularly on the market, but if anybody can get it, I think it is a very good method.

Then there is another objection to that also, that I mentioned in my paper, and I think really it is the reason that these magnetic commutation machines have not been successful. When speaking in the paper of the machines that spark at any position of the brushes, I attribute that to the fact that the commutation was entirely regulated by the inductance or impedance of the coil and the reversal E. M. F., and therefore the density in the brush contact might vary even if the current were reversed, and if the brush density does vary, the energy of commutation increases necessarily, and if, therefore, you commutate by means of a pole-opposing inductance, you will get a variation of current which is not the best for low energy at the contact surface, and the energy may be concentrated at the point near the edge of the brush, where it would do most harm.

MR. DUNN:—With regard to the first point that Mr. Reid makes as to the resistance of the brush, stating that he did not know but that my cases had been accompanied by a diminution of the brush contact and therefore a change of the brush contact resistance, I would say that I have had a machine that sparks with a copper gauze brush of 30 mesh and I have put upon the same machine a brass gauze brush of the same dimensions and mesh and it stopped the sparking. Now I think that leaves very little chance for change of contact resistance.

MR. REID—May I interrupt you a moment? What I meant was not change in the area, but change in the resistance due to change in the substance. I did not mean to say that you had changed the contact area of the brush, but simply that the change in the substance of the brush itself with the same contact area would change the contact resistance.

MR. DUNN:—As to that, I do not know. But Prof. Crocker had some experiments made a year or so ago upon the contact resistance between moving metal surfaces of copper and various brushes bearing upon it, including carbon and various metals, and as I remember it, the contact resistance did not vary very much between the different metals. We can certainly get the information from that source.

Now with regard to the aspersions upon this two volt reactance. I have designed machines that have sparked, but in this case you are attacking one that does not. The armature wound for 500 volts, has even between four and five volts reactive drop, and I have run it at 60 per cent. overload with practically no sparking, and at 20 per cent. overload with absolutely no sparking.

With regard to the damage being done by the sparks at the toe of the brush, I thoroughly agree with Mr. Reid. He has brought out a very valuable point. Commutators can be cut very badly and injured so that the machine is useless, without a spark appearing at the brush until after the harm has been done.

With regard to the contact resistance, I have before me some results of a test I made this afternoon, thinking to compare the contact resistance of graphite with the contact resistance of carbon which I knew about. With carbon, the contact resistance is not constant, but rises very rapidly at first with the least motion of the armature. The armature, if stationary, might have a drop across it of 4.2 volts when the slightest motion by the hand would bring that up to 4.4 volts, but after that first rise has taken place suddenly, then it seems to go on evenly. Now this is for carbon, and gives two-tenths of a volt due to change of contact resistance with speed, out of a reactive drop of 2 volts; which shows if we do make an error in estimating the change of contact resistance, it will not affect our result very largely; but the same cannot be said of the graphite brushes. The graphite brushes behave in the most extraordinary manner. The volts may go up a whole volt when you start to turn the armature the smallest amount. I suppose that is due to the nature of the graphite and one reason why telephones are so good.

With regard to magnetic commutation, I was only indulging a little. I know that the magnetic commutation has not been successful so far, but that does not mean that it cannot be, and I simply hope to see it successful.

The Chairman:—Gentlemen, it seems to me that the question whether the contact resistance or the internal resistance of the brush is larger, is a more relative one, and depends on the kind of brushes used. With ordinary carbon brushes, I know that the internal resistance of the brush is entirely negligible compared with the contact resistances. But with these Wirt brushes with insulation between the leaves, the internal resistance of the brush may be far larger than the contact resistance, although I have never tested them. Now, the effect on the commutation must be undoubtedly very nearly the same whether the resistance is in the contact or internally. In regard to the question whether the contact resistance depends on the material or not, I may state that it does depend. The contact resistance of the ordinary commutator brush carbons is many times larger than the contact resistance of copper brushes. Curiously enough, the contact resistance of graphite is very similar, but the magnitude of the resistance drops given by Mr. Dunn is entirely different from anything I ever found at the current densities commonly used. The contact resistance voltage of continuous current machines is found something like one volt or more, but not tenths of volts. It varies slightly with the speed, not very much. This resistance applies to the carbon brush on a commutator running at some thousand feet a minute, not standing still. Standing still, the resistance is very much less.

Mr. Dunn:—I would like to bring out one further point that may be of interest. It has a bearing on the fact that the resistance of the brush and not of the contact has to do with the reversal of the coil. I do not mean that the contact resistance has no effect, but the volumetric resistance does have a large effect. I have taken sparking which would occur with a brush of the kind shown at Fig. 4, and have stopped it by using a brush of about the same spread on the commutator, but inclined as at B. That would make, you see, the reversing current volume, which is thrown over into the toe of the brush, discriminate between the toe and the heel of the brush, and help the reversal by having a longer path of consequently higher resistance at the toe. If it is true, then the form of brush which bears on the commutator in the opposite direction, as in C, Fig. 4, would be less valuable for stopping sparking than the other, but I have never made any measurements or experiments on this.

Dr. A. E. Kennelly:—One of the principal points in this very interesting paper is one that seems to me to have occupied less attention than it deserves. The theory of sparking considered in the paper is more than the theory that has generally been advanced, by reason of the melting process. The theory considered here is the theory that has generally been advanced plus the effect of melting the copper and discharging that melted copper across the gap. In other words, Mr. Reid has taken the ground that the damage is done before the brush leaves; whereas according to the ordinary theory, the damage is not done until the brush has left the commutator bar. It seems to me that this can scarcely be differentiated from the ordinary theory, because whenever the conditions are present which will produce a powerful discharge at the moment of leaving the bar, it seems to me that you have the conditions which will produce a very powerful current and produce this very melting he speaks about. In other words, you cannot have a powerful current density at the edge of the commutator segment, such as would melt it, without having the conditions favorable to producing the very discharge that the spark ordinarily has been considered to be. The cause of

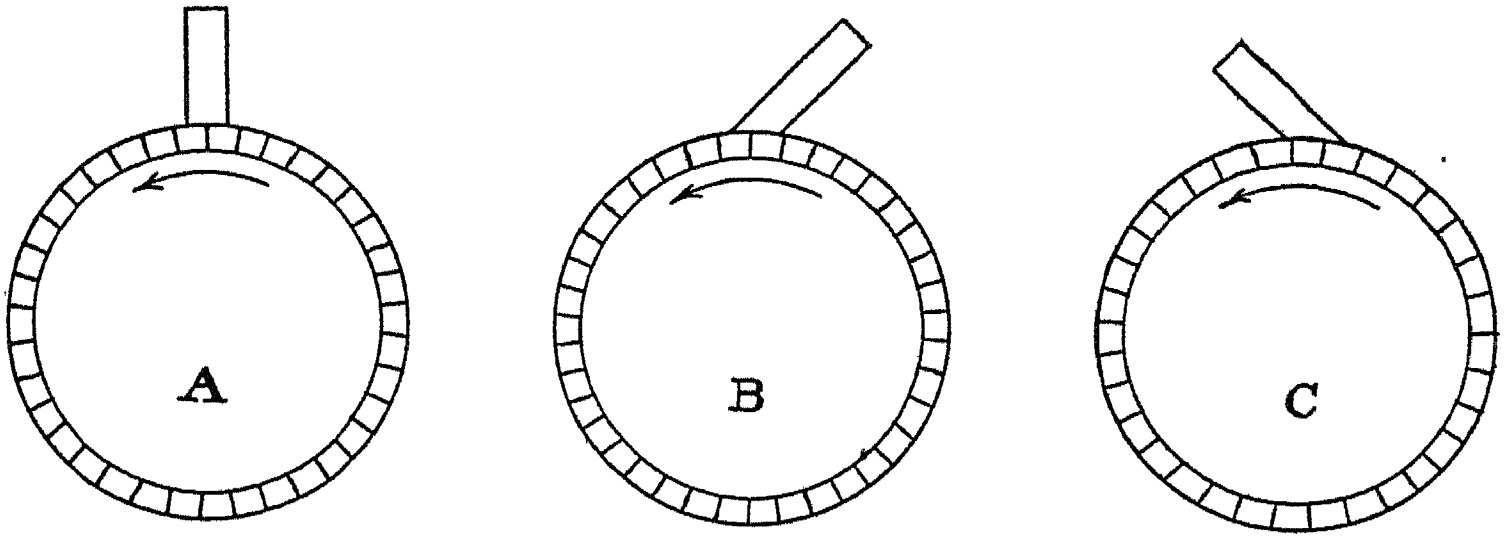

Fig. 4.

sparking, we all agree upon as being a difference of potential between the edge of the brush and the edge of the commutator segment, and that difference of potential is ordinarily due to self-induction of the coil and the commutation. The electro-motive force of the self-induction is that which produces the discharge. That electro-motive force can be neutralized in two ways; first, by the resistance method, by opposing to it a drop of pressure produced in the toe of the brush producing an electro-motive force available for opposing the electro-motive force of self-induction. The second way is by introducing into the moving coil under commutation, an E. M. F. induced by magnetic flux.

In some cases that is done by forcing the brushes forward. In other cases it is done by employing a separate pole, as in the Ryan and Sayers machines. When you get a sufficient difference of potential at the point of discharge to obtain a powerful spark, surely you are likely to have a sufficient current density at the edge of the commutator bar to produce this high temperature and melting and volatilizing. So do not these two effects of sparking and melting merge together, and shouldn't they be considered as parts of the same phenomenon, rather than two separate phenomena which Mr. Reid in his paper leads us to suspect.

This interesting method of determining the reactive drop in the armature of the machine described by Mr. Dunn, cannot of course, give the reactance of the whole armature, but only the apparent reactance of the armature, when working as a continuous current generator, including as Mr. Steinmetz has pointed out, the variable surface contact resistance under conditions of vibration and rotation, the conditions of variable surface on the brush, and the conditions of inductance in one coil, as modified by the local surroundings, since if you put the same armature into the pole-pieces, the apparent inductance of the coil is liable to be varied. But the method shows how carefully we should distinguish between what is commonly called the resistance of the armature including the brushes, when stationary, and when running.

MR. REID:—In regard to Dr. Kennelly's contention that the melting would not occur unless there was sufficient energy at the edge of the brush to draw sparks, there was one kind of commutation mentioned, where there would be no sparking with destruction of the commutator, and on the other hand there was another where there would be sparking without any injury to the commutator. The first case was where the entering segment had a higher current per square inch than the receding one, where the copper was melted in the front part of the segment and carried over onto the back. That is where there is no spark. The commutator gradually wears away and the spark appears after a while. Then the other case was where the current is not entirely reversed by the time the segment leaves the brush, but the segment leaves the brush with a small difference of potential, and the spark jumps across and does no harm, because the main part of its energy is dissipated in the air between the segment and the brush. Unless there is melted copper there through which to draw an arc, as you do in an arc lamp, no harm will be done. That was the principle I brought out, and I think still that that is a correct one.

MR. DUNN:—In vindication of my method, the experiments and the computations also will show that it does not include a number of uncertain quantities, or quantities of importance in comparison with the result. Now, in this armature our reactive drop (which is the difference between the drop when the armature is standing still, and when it is moving) is about two volts. With carbon brushes in which the variation of contact resistance is small, the measured valueof the reactance comes out about three-quarters of the computed value after all allowances have been made for contact resistance, brush resistance and variation of contact resistance with speed. I think this remarkably close in view of the very high frequency which introduces uncertain elements and is a proof of the method.

MR. KENNELLY:—In regard to what Mr. Reid has said, no doubt it is true when you get sufficient current density at the edge of the commutator bar you will melt it, and no doubt it is true that when you enter a segment with too much current density, you will melt the segment. But when the brush leaves a bar, if there be any considerable difference of potential between the two, there will be a spark. The question is, whether so soon as there is much spark discharge, there will not also be sufficient heat to melt the edge of the bar.

MR. REID:—In the case of the Ruhmkorff coil, or any other coil of that character, you can get sparks all day, and it will not hurt your points. You can get large sparks, and the points may be mere needle points, and they will stay there all day. You can get the same thing in commutation. You can get sparks going from the segment to the brush, and provided there is no melted copper or volatilized copper to form an arc, you can get sparks all day that will not hurt your commutator. We often have what I call the blue spark, and we have it on railway motors all the time, —I do not mean on all of them, but we have it on railway motors that will run right straight along, year in and year out, with the spark,—and the commutator will be just as hard and glossy as you like. The spark is no indication of injury. The only injury that is done is when the copper is melted before the brush leaves the segment. We may have any amount of sparking, not vicious sparking, however, so long as you please, (I might say, if it is a blue spark), and it will not injure the commutator.

THE CHAIRMAN:—The best instance of such a harmless spark is the open coil arc light machine. That machine requires for stable commutation a spark of considerable length, and the spark runs on all night and day without hurting the commutator, because the current is limited—not sufficient to volatilize the copper. That brings up another feature, namely, that Mr. Reid's paper and the whole discussion have dealt with one kind of commutation only, which, however, is not the only kind, because a very large class of machines, the arc light machines, commutate in an entirely different manner. With them it is neither resistance commutation nor magnetic commutation, or, as it is perhaps preferable to call it, magnetic field commutation; but a different phenomenon, which would take too long to discuss here, but which might very properly form the basis of a separate paper. It takes place in open coil arc machines, alternating current rectifiers and self-exciting synchronous motors or alternators. Thus, you see, the commutation discussed in this paper is not the only kind of commutation which exists.

Dr. Wm. E. Geyer:—I should like to ask the gentlemen who have discussed this matter, whether in their treatment they have considered another electromotive force which I think has not been mentioned. I have reference to thermo-electric electromotive force. That we all know is very small, and we ordinarily despise it. But in this case where the junction of two similar metals is at the melting point of copper, and the other ends are relatively cold, I imagine we might get quantities worth considering.

The Chairman:—I may answer that question in the negative, in so far as I cannot see how you can get the effect of thermo-electromotive force, since having two couples in series, whatever electromotive force you get on the positive brush must be opposed by an opposite electromotive force at the negative brush, so the result must be zero, I should think.

Dr. Geyer:—I have reference to the action at one of the brushes, not to the machine as a whole, but to the actions around a single brush.

The Chairman:—I do not know of any tests made in this respect.

If there is no further discussion on this subject we will proceed to the second part of the programme, an exhibition of "Wireless Telegraphy." But I would suggest that in view of the very interesting paper, a vote of thanks to Mr. Reid would be proper.

Mr. Dunn:—May I have the pleasure of moving a vote of thanks from the Institute to Mr. Reid for his very able paper.

The Chairman:—The motion is carried. I thank Mr. Reid here in the name of the Institute, for his very interesting and valuable paper which I am sure will be of importance and value in our Transactions even after years.

The second part of the programme is now in order, an exhibition of "Wireless Telegraphy." I will call upon Dr. Kennelly to take the Chair.

WIRELESS TELEGRAPHY.

December 15, 1897.

MR. W. J. CLARKE:—Mr. Chairman and gentlemen: Having been requested this evening to give you an exhibition of the Marconi apparatus, I am pleased to be able to say that I am in a position to do so. I think perhaps it might be well to give you a short explanation of the apparatus which we use. In the first place, we have here on the front of the base, a Marconi coherer consisting of a small glass tube, fitted with silver plugs connected to platinum wires at the end. These plugs are very close together, about the centre of the tube, the intervening space being filled in with nickel filings. I have found that it is entirely unnecessary to either exhaust or seal the tube. I also find that we can use almost any kind of metal for the filings. When the cohesion is examined under the microscope, I find that what we have to provide for is the proper size of the filings, and not the proper kind of metal. This coherer is placed in series with this relay which is of about 1200 ohms resistance, and made extremely sensitive, more so than the ordinary Morse relay. In series with it, also, are two cells of small dry battery placed in the base. These are arranged so that we can use either one cell or two, the object of this being that when the cells are new, we can use only one in order to prevent corrosion of the filings where they cohere. As the cells grow older we simply throw our *a* switch, and use two cells. This sounder is a 20-ohm instrument. It is placed in multiple with this cohering apparatus consisting of a 20-ohm vibrator placed in the base. The local battery consists of three cells of dry battery arranged as with the main battery, so that we can either use one, two or three of the cells. This Morse key is simply used in order that we may see that the apparatus is in proper condition. Pressing this key short-circuits the coherer. Our transmitter consists of an eight-inch induction coil. A much smaller one, though, is all that is necessary for a short distance. This coil has its secondary terminals connected with two brass balls, each an inch and a half in diameter. These balls are brought into close proximity, in fact in most cases touching two large brass balls, four inches in diameter. The large balls are securely cemented in the ends of a rubber tube, and the distance between them on the inside of the tube is about one-thirty-second of an inch. The space between the balls in the tube is filled with the purest quality of vaseline oil, and the moment that we close the circuit through the primary of the coil the electric waves generated strike the coherer, the filings cohere, and the resistance is sufficiently reduced to operate the relay. Sometimes we have trouble with this particular instrument, not on account of the system being imperfect, but on account of the fact that it is the first piece of portable apparatus that I know of built in this country, and of course you understand that the first piece of apparatus is liable to imperfection. I think now that everything is in proper shape, and I will proceed to the other room and close the circuit of the primary of induction coil, and I think you will see the receiver respond, and after doing this we will close the doors and work the receiver through the glass doors.

[Apparatus shown in operation.]

THE CHAIRMAN:—[Dr. Kennelly]. Gentlemen, you have witnessed an interesting exhibition, and I am sure that many must be desirous of asking Mr. Clarke some questions upon the difficulties he has had to encounter in making this instrument, and the various matters he has found necessary to take into account. I am sure that if he is as ready to answer as he has been ready to describe the apparatus that he will respond.

MR. GANO S. DUNN:—I should like to ask whether the circuit remains closed while the shower of sparks is passing, and also, if Mr. Clarke would describe the action of the coherer.

MR. CLARKE:—I would like to say that with proper adjustment, the circuit remains closed as long as the primary circuit of the induction coil is closed, and as long as the vibrator of the induction coil is in action. Unfortunately the adjustment which we have on our decohering apparatus in this instrument is not sufficiently under control, so that I cannot get the fine adjustment necessary for transmitting intelligible Morse signals, but this is simply a question of proper adjustment. Now with regard to the coherer, as I said before, it simply consists of two conductors separated by a very short interval, this space being filled with metallic filings. The filings are of such a size and the distance apart of the conductors is such, that while the filings are lying loose, the resistance through the tube is very high indeed. But the moment that the filings cohere, the resistance is very much reduced, so much so that the current in series with the relay is able to pass to a sufficient extent to operate the relay. I may say that I have been so very busily engaged in getting a smaller and less expensive set of apparatus ready for the market, that I have not had an opportunity to experiment very largely with the question of the distance, but I expect during the next week to be able to accomplish something in that direction.

MR. DUNN:—I have done a good deal of telegraphing and am familiar with the frequency requisite to get all the signals in. For instance, when the operator is sending very rapidly, his "e" dot, by the time it reaches the other end may be only a very small fraction of a second. I noticed the frequency of your coil was readily observable, I could almost count it by beats, and I wanted to inquire how long one discharge of the coil would cause the filings to cohere, and hold the circuit closed.

MR. CLARKE:—The coherer, when in proper shape, in which this hardly is, is so very sensitive that it is not necessary to have a vibrator on the coil at all. It is simply necessary to have a Morse key. The coherer responds the moment you close the circuit, only in this case, of course, it simply coheres and decoheres instantly, and the circuit of the sounder is closed and opened.

Mr. Dunn:—If when you close your key on the induction coil that causes the filings to cohere, and then decohere immediately, your sounder here would make its down click, and be followed by its up click when the key in the other room has not risen.

Mr. Clarke:—Yes.

Mr. Dunn:—Then you would have to use some different system from the ordinary Morse for sending.

Mr. Clarke:—No, because when we use the vibrator on the coil, and everything is in proper adjustment, the filings cohere as long as our coil is working, and decohere the moment we stop it by opening our key.

Mr. Dunn:—The vibrator frequency is about 800 a minute.

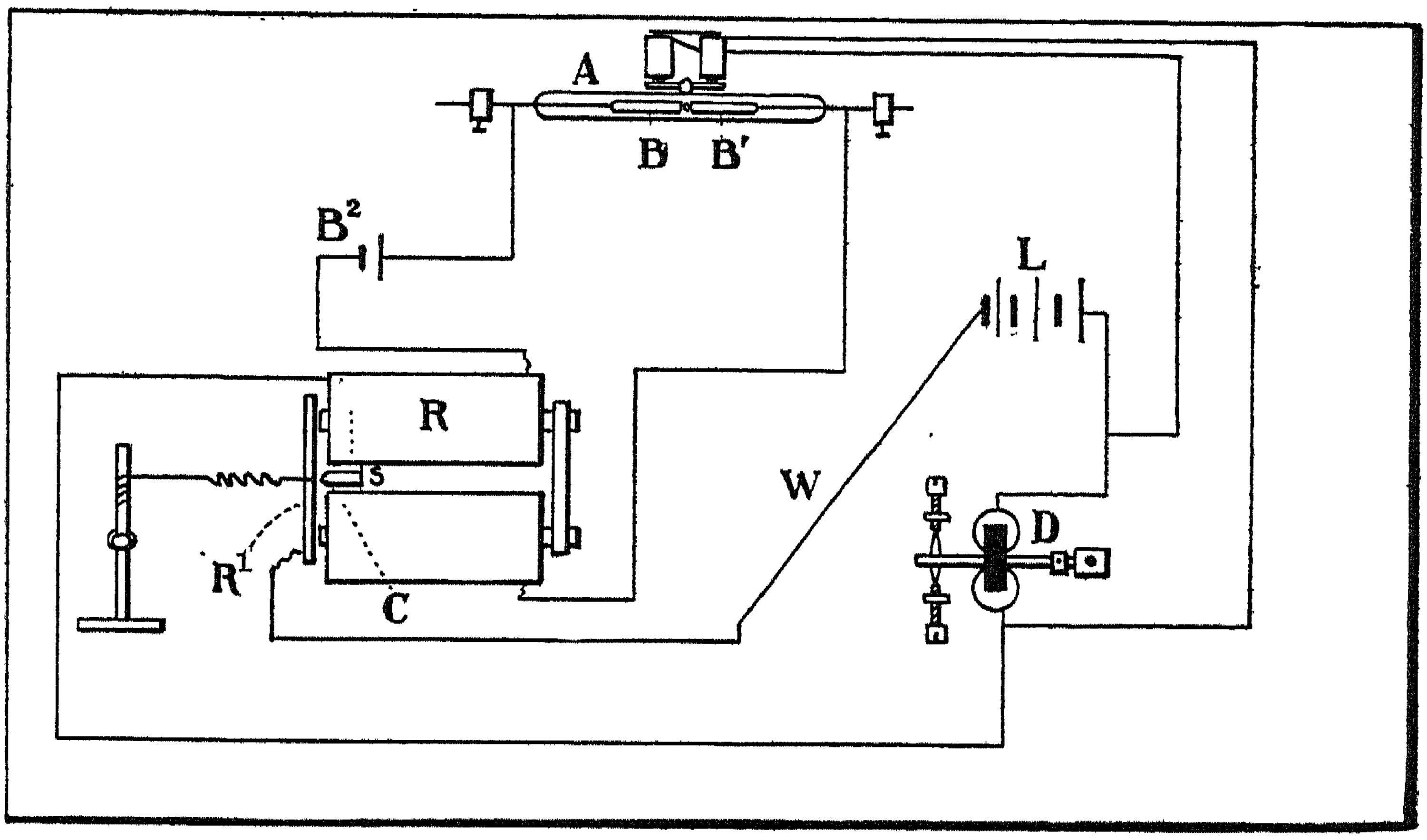

Diagram of Marconi Apparatus.

Mr. Clarke:—Well, I may say that the coil we are using is not the coil that we use for quick signaling. We use a Tesla coil for that purpose, a very high-frequency coil.

The Chairman:—I might suggest for the benefit of some who may not be familiar with the subject, that if you sketch the outline of the connection on the board it may help.

Mr. Clarke:—I will do that, I might say that at some future time I would be very glad to show you the stereopticon diagrams on the sheet, of the different classes of this apparatus we are making up. It is a little difficult to explain it on the blackboard, but I will do the best that I can. Here we have the coherer A somewhat enlarged. These B B′ are the silver plugs. The filings are between the ends of those plugs. The main battery B² is connected to one end of the coherer. The other terminal of the battery is connected to one terminal of the 1200-ohm relay R. The other terminal of the relay is connected to the coherer. Now when the apparatus is in its normal condition, the relay is so adjusted and the resistance of the filings is such, that the current from the battery will not pass to a sufficient extent to operate the armature of the relay, but when the waves from the transmitter strike the filings and they cohere to each other, and also to the silver plugs, as examination under the microscope shows that they do, the resistance is so reduced as to allow sufficient current to pass from this battery to operate the relay. The moment the relay operates, it pulls up its armature, making the contact C. The moment this contact is made, the current from the local battery L traverses the wire W to the armature of the relay R¹, from the armature across the contact to the screw S, back to the sounder D and back again to the battery. Now once the filings have responded to the waves and cohere, they will remain cohering unless we have some means of decohering them. In order to accomplish this, we have a vibrating hammer which strikes the tube. This vibrator is placed in multiple circuit with the sounder. They are both of comparatively high resistance.

MR. EDWARD DURANT:—I would like to ask what is the greatest distance at which you can get communication?

MR. CLARKE:—I may say that I have not tried the instruments at very long range. I have not had either the time or the opportunity. But I understand from the reports coming from the other side, that Mr. Marconi has had no difficulty in transmitting intelligible signals twelve miles.

MR. MACGREGOR:—I should like to ask one or two questions. The first is,—does it make any difference as to what the relative position of the tubes containing the filings is? Is the position you have it in all essential?

MR. CLARKE:—I have not found that it is.

MR. MACGREGOR—The second thing I want to ask is, whether there is any fixed relation between these two pieces of apparatus. In other words, would any other induction coil produce the same effect as this one, or are these two instruments related so as to form a pair? If intelligence transmitted from one piece of apparatus could be read by any one of a hundred machines, this method of telegraphy would have its disadvantages.

MR. CLARKE:—In the first place, I have not found using the short ranges over which I have tried the apparatus, that it makes any difference in what position either the receiver or transmitter is placed. In regard to their being any tune, as we may call it, between the transmitter and receiver, I may say that Marconi claims that it is absolutely necessary to have the transmitter and the receiver in what we might call synchronism. In order to accomplish that, he takes two strips of copper, each about half an inch in width, and attaches them to the end of his tube, one on each end. These strips of copper he claims have been shortened or lengthened in accordance with the frequency of our transmitting apparatus. In order to ascertain what is the proper length, he takes a piece of glass and pastes upon it a strip of tin foil about half an inch in width, and two or three feet in length. He divides this strip in the centre with a very sharp knife. He sets his transmitter in a dark room and places this testing apparatus in front of it, at a few yards distant. He operates his transmitter, and when he does so, the same as in the experiments of Hertz, he notices small sparks passing across between the divided tin foil. He moves his tester further from the transmitter until the sparks entirely disappear. Then he cuts off, say half an inch, from each end of his tin foil and immediately the sparks reappear. He goes further, until the sparks disappear again, and he keeps on cutting down each end of his tin foil, until he finds that he is working in the other direction, and that if he cuts it any more, he simply has to go back closer to the coil in order that the sparks at this point will reappear. Then he finds he has got the proper length. Accordingly, he cuts what he calls the wings of the coherer nearly the same length as these two pieces of tin foil. I may say that in the comparatively small distance over which I have tried the apparatus, I have not found it necessary to have any wings on the tube at all, or that it is necessary to have the apparatus in any kind of synchronism, I find that some recent writers in the London *Electrician* bear me out in this. I see it stated that in one of the exhibitions given by Mr. Marconi, or some of his associates, that in order to show how readily the waves would go through a piece of iron, the coherer was placed in an iron box, and in order to place it there, it was necessary to remove the wings, but the coherer responded just the same.

DR. SAM'L SHELDON:—I would like to ask if it is essential that you should have silver for the two electrodes.

MR. CLARKE:—The only object, as far as I can see, is simply to keep the points of contact clean.

DR. SHELDON:—Then the object of a vacuum would be to prevent the silver from oxidizing.

MR. CLARKE:—Yes, and I may say in this connection too, that experiments have been tried with putting the filings in hydrogen gas, but it was found that they speedily became too bright and clean, so much so that they cohered all the time. If the filings are examined under a microscope and the waves are acting upon them, it will be noticed that the moment they decohere you will see little bright spots where the particles of metal have been touching each other. Those bright spots rapidly disappear.

MR. C. T. CHILD:—I would like to ask if that decoherer is in the nature of an electro-magnetic vibrator.

MR. CLARKE:—Yes.

MR. CHILD:—How do you shield the coherer from the waves sent out from that instrument?

MR. CLARKE:—We do not find that it affects them in the least.

MR. CHILD:—I should think that those waves would affect it.

MR. CLARKE:—Well, Mr. Marconi claims that it does. I have not found any effect at all. Perhaps it is because I have guarded against that by cutting down the sparks at the contact with resistance coils, and also placing a resistance across the terminals of all the magnets.

A MEMBER:—I fancy that the resistance must be very low with those metal filings there, so low that the variation must be very small as we find at once in telephone experiments where we use metal filings. May I ask what the resistance is of that coherer?

MR. CLARKE:—I may say that although I have the facilities, I have not had the time to make a thorough test in that direction and I can only guess at what the resistance really is. I expect very shortly to devote very considerable time in making a thorough test.

THE CHAIRMAN:—It is very high, isn't it?

MR. CLARKE:—I hardly think so, because you will see we have a resistance in the relay of 1200 ohms, and one cell of dry battery is all that we require to operate it. In fact if we use silver filings it is difficult to get them to decohere enough to interrupt the flow of current. I should have stated that silver is the only metal I have found that is too sensitive.

MR. WINTRINGHAM:—How so?

MR. CLARKE:—If we use silver filings we find it almost impossible to adjust the apparatus so that the circuit will remain open and then close when the waves strike it. Silver filings are so very clean and bright, that they form a very low resistance across the plugs in the tube, much lower than nickel or any other metal that I have tried. I have not tried gold or any metal of that kind. I do not know how they would act.

THE CHAIRMAN:—If there are no further questions, I feel sure that you will endorse my recommendation that a vote of thanks be extended to Mr. Clarke for his kindness in exhibiting the apparatus, and in so patiently answering all our questions prompted by a very natural curiosity. I need hardly put that to vote. I think I am justified in extending that vote of thanks.

MR. ALBON MAN:—Will the gentleman answer one question? The origin of waves seems to be provided for between the large balls in the rubber tubes. Why are not other waves generated between the small balls and the large ones, or are they generated, and do they have the same effect as the ones in the tube? I understand that sparks pass between the terminals of the small balls and the large ones.

MR. CLARKE:—Yes.

Mr. Man:—Are they not a source of electrical waves?

Mr. Clarke:—In regard to that I can hardly say; I have not experimented far enough. Mr. Marconi claims that it is necessary not only to use two balls four inches in diameter in the tube, but also use the other balls of the same size. Now I find that over the short distance that I have worked the apparatus, it is not necessary even to have the small balls at all. All that is necessary is to connect the terminals of the coil to the large balls, and I have used a coil of only one inch spark capacity. I feel quite positive that a coil of that size is all that is necessary for transmitting this distance.

Mr. Man:—I would like to know also if the diameter of the large ball and its mass, is a necessity to the transmission of the waves, or the production of the waves. Has the mass of the balls anything to do with the force of the waves?

Mr. Clarke:—I can only say in regard to that, that I have followed Mr. Marconi's experiments very closely. I have only so far constructed a transmitter with the four inch solid brass balls. Marconi claims that it is absolutely necessary to have solid balls for long distance transmission, and that with hollow balls, the distance over which we transmit will be less than half. My own impression is, that hollow brass spheres filled with lead, or other inexpensive metal, would be just as good, and we are going to experiment with that shortly, and also with the smaller spheres, on account of the larger spheres being very expensive and very heavy.

Mr. Man:—Hertz found his electrical waves produced as readily from small balls, or even any kind of a spark as from larger masses. It was for that reason that I asked the question.

Mr. Clarke:—Knowing the results of the experiments of Hertz, I am of the opinion myself that the size and mass of the ball does not make the difference that is claimed for it, and for that reason we are going to experiment in order to determine that accurately.

Mr. Hamblet—I move a vote of thanks to Mr. Clarke for the very interesting exhibition that he has given us this evening.

[The motion was carried, and the meeting adjourned.]

OBITUARY.

Frank Hayes Dorr, (associate member May 15th, 1894) was born in Somersworth, N. H., June 5th, 1869. The record of his life, though brief, is the story of earnest endeavor, of high aspiration and of large achievement.

He attended the public schools, and was graduated from the Somersworth High School in 1887. He then entered the Massachusetts Institute of Technology, and was graduated in June, 1891, receiving the degree of Bachelor of Science in Electrical Engineering.

The next month he entered upon the expert course in electrical engineering in the Thomson-Houston electrical factories, in Lynn, Mass., remaining in the employ of the company a year. He was then transferred in 1892 to the Chicago office of the General Electric Company as an expert engineer.

During the World's Fair he had charge of the construction and operation of the two electric fountains. These fountains were the largest of the kind ever built, and in their construction were involved a great many new ideas and electrical and mechanical features, calling for the highest kind of engineering ability. There was perhaps nothing at the fair which excited so much interest and admiration as these fountains, and the result was very largely due to Mr. Dorr's splendid management of the intricate apparatus. He afterwards superintended the removal of one of these fountains to the Midwinter Exposition in California, and put it in position and operated it throughout the fair.

After this, Mr. Dorr returned to Chicago, and was continued with the General Electric Company on expert work in connection with multiphase apparatus, which necessitated frequent trips into many parts of the country, building and equipping electric railroads and other enterprises. He was in charge of the installation of three-phase machinery at Austin, Texas, in connection with the water power plant owned by the city, and also had to do with various other important, difficult and intricate electrical installations.

It is possible that the sudden change of climate to which he was subjected, together with the alternations of outdoor and indoor work, prepared the way for the disease, consumption, which resulted in his death at Somersworth, January 8th, 1897.

Mr. Dorr was an electrical engineer of very high class and of exceptional ability, and had his life been spared, his name would have appeared frequently in connection with the advance in electrical development. He was a man of high integrity and unswerving fidelity. Possessing a sunny and genial nature, he had won the friendship of a large circle of friends, who sincerely mourn his loss.

S. E. W.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

CATALOGUE OF MEMBERS.

APRIL 1ST, 1898.

HONORARY MEMBERS.

Name.	Address.	Date of Membership.
KELVIN, *Lord*,	*LL.D.*, *F.R.S.S.L.* and *E.* The University, Glasgow, Scotland,	H.M. May 17, 1892
PREECE, WM. H. *F.R.S.*	Electrician, General Post Office, London, Eng. Residence, Gothic Lodge, Wimbledon.	H.M. Oct. 21, 1884

Total, 2.

MEMBERS.

ABBOTT, ARTHUR V.	Chief Engineer, Chicago Telephone Co., 203 Washington St., Chicago, Ill.	A Oct. 21, 1890 M Jan. 16, 1895
ACHESON, EDW. G.	President, The Carborundum Co., Niagara Falls, N. Y.	A Jan. 3, 1888 M May 1, 1888
ADAMS, ALTON D.	Electrical Engineer, 620 Atlantic Ave., Boston, Mass.	A April 18, 1893 M Jan. 17, 1894
AHEARN, THOMAS	Ahearn & Soper, Electrical Supplies, Ottawa, Ont.	A July 12, 1887 M Sept. 6, 1887
ALBRIGHT, H. FLEETWOOD	Electrical Engineer, Western Electric Co., New York; residence, 60 Sayre St., Elizabeth, N. J.	A Sept. 27, 1892 M June 20, 1894
ALMON, G. H.	Electrical Engineer and Contractor, Montpelier, Vt.	A Sept. 20, 1893 M Mar. 21, 1894
ANDREWS, WM. S	Manager Central Station Sales, General Electric Co., Schenectady, N. Y.	A Mar. 5, 1889 M April 22, 1896
ANTHONY, PROF. W. A.	(*Past President.*) Consulting Electrician, Cooper Union, New York, N. Y.	A Dec. 9, 1884 M Jan. 6, 1885

Name.	Address.	Date of Membership.
ARNOLD, BION J.	(*Manager.*) Consulting Electrical Engineer, 1541 Marquette Bldg. and 4128 Prairie Ave., Chicago, Ill.	A Oct. 25, 1892 M Nov. 15, 1893
AYER, JAMES I.	General Manager American Electric Heating Corporation, 611 Sears Building, Boston, Mass.	A May 19, 1891 M April 19, 1892
AYRES, BROWN	Professor of Physics and Electrical Engineering, Tulane University, New Orleans, La.	A Dec 16, 1891 M Mar. 15, 1892
BADT, LIEUT. FRANCIS B.	Electrical Engineer, Firm of Meysenburg and Badt, 1522 Monadnock Block and 6506 Lafayette Ave., (Englewood), Chicago, Ill.	A April 19, 1892 M Mar. 25, 1896
BAILLARD, E. V.	Manufacturer of Electrical Instruments and Fine Machinery, 106 Liberty St., New York City.	A Dec. 3, 1889 M Jan. 16, 1895
BALDWIN, BERT L.	Mechanical and Electrical Engineer, The Cincinnati Street R'way Co., 72 Perin Bldg., Cincinnati, O.	A April 22, 1896 M Nov. 18, 1896
BATCHELOR, CHAS.	Electrical Engineer, 33 West 25th St., New York City.	A June 8, 1887 M July 12, 1887
BATES, J. H.	Assistant Engineer and Draughtsman, with C. J. Bates & Co., 126 Liberty St., New York City, and 321 Hudson St., Hoboken, N. J.	A Sept. 6, 1887 M Oct. 1, 1889
BAYLIS, ROBERT NELSON	The Baylis Co., 99 Cedar St., New York City.	A Oct. 1, 1889 M May 17, 1892
BEDELL, DR. FREDERICK,	Assistant Professor in Physics, Cornell University, Ithaca, N. Y.	A April 21, 1891 M May 19, 1896
BELL, PROF. A GRAHAM	(*Past President.*) 1331 Conn. Ave., Washington, D. C., and Baddeck, N. S.	A April 15, 1884 M Oct. 21, 1884
BELL, DR. LOUIS	Electrical Engineer, Boston, Mass.	A May 20, 1890 M June 18, 1890
BENJAMIN, PARK	Electrical Expert and Engineer, 203 Broadway, N. Y. City.	A Dec. 16, 1891 M Feb. 16, 1892
BERNARD, EDGAR G.	Electrical Engineer, President, E. G. Bernard & Co., 43 4th St., Troy, N. Y.	A. Jan. 5, 1886 M July 12, 1887
BERTHOLD, VICTOR M.	Patent Department, American Bell Telephone Co., 125 Milk St., Boston; residence, 16 Upton St., Cambridgeport, Mass.	A May 17, 1892 M May 21, 1895
BILLBERG, C. O. C.	Electrical Engineer, 3300 Arch St,. Philadelphia. Pa.	A Mar. 21, 1894 M Feb. 27, 1895
BINNEY, HAROLD	Patent Solicitor and Expert, 31 Nassau St., New York City.	A Sept. 16, 1890 M Dec. 16, 1890
BIRDSALL, E. T. *M. E.*	Consulting Electrical Engineer, 26 Cortlandt St., residence, 56 West 38th St., New York City.	A June 8, 1887 M Nov. 1, 1887

Name.	Address.	Date of Membership.
Bishop, James Draper	Mechanical Engineer of the Safety Insulated Wire and Cable Co., 229 W. 28th St., New York City.	A Dec. 16, 1891 M Oct. 25, 1892
Blades, Harry H.	Electrical Engineer, 419 Cass Ave., Detroit, Mich.	A April 19, 1892 M May 21, 1895
Blake, Francis	Auburndale, Mass.	A Sept. 3, 1889 M Oct. 1, 1889
Blodgett, Geo. W.	Electrical Engineer, B. & A. R. R. and Consulting Electrician, Boston, Mass.	A July 12, 1887 M Sept. 6, 1887
Blood, John Balch	Blood and Hale, Consulting Engineers, Room 22-A, Equitable Building, Boston, Mass.	A June 20, 1894 M Dec. 18, 1895
Boileau, Willard E.	Superintendent and Electrician, Brush Electric Light & Power Co., Columbus, Ga.	A Sept. 19, 1894 M Mar. 25, 1896
Bosch, Adam	Sup't Fire Alarm Telegraph, Newark, N. J.	A April 15, 1884 M Jan. 6, 1885
Bottomley, Harry	Electrical Engineer, Supt., Marlboro Electric Co., Marlboro, Mass.	A April 2, 1889 M Jan. 22, 1896
Bourne, Frank	Electrical Engineer, 26 Cortlandt St., New York City.	A April 21, 1891 M Nov. 15, 1892
Bowman, Fred. A.	Supt., New Glasgow Electric Co., New Glasgow, Nova Scotia.	A May 19, 1891 M Nov. 21, 1894
Boyer, Elmer E.	Foreman, Testing Department, Lynn Works, General Electric Co., Lynn, Mass.	A Sept. 25, 1895 M Mar. 25, 1896
Boynton, Edward C.	Electrical Dep't, N. Y., N. H. & H. R. R., New Haven, Ct.	A Aug. 6, 1889 M Nov. 24, 1891
Bradley, Chas. S.	(*Vice President.*) Electrical Engineer, 44 Broad Street, New York City.	A May 24, 1887 M Dec. 6, 1887
Brenner, William H.	Constructing Engineer, Care of Frazar & Co., Yokohama, Japan.	A Sept 20, 1893 M Mar. 21, 1894
Brinckerhoff, Henry Morton	Electrical Engineer, Metropolitan West Side Elevated R. R.; 258 Franklin St., Chicago, Ill.	A Sept. 23, 1896 M Dec. 16, 1896
Broadnax, Francis	Electrical Engineer, Blake and Williams, 362 West Broadway, New York City; residence, 28 Walnut St., Montclair, N. J.	A Jan. 17, 1894 M Jan. 16, 1895
Brooks, Morgan	President and Manager, The Electrical Engineering Co., 249 Second Ave., South; residence, 2950 Park Ave., Minneapolis, Minn.	A May 20, 1890 M June 17, 1890
Brown, Alfred S.	Electrical Engineer, Western Union Telegraph Co., 195 Broadway, P. O. Box 856, New York City.	A Mar. 18, 1890 M Feb. 21, 1893
Brown, Edward D.	General Inspector, American Telephone and Telegraph Co., 18 Cortlandt St , New York City; residence, 75 Hicks St., Brooklyn, N. Y.	A Sept. 19, 1894 M Nov. 20, 1895

Name.	Address.	Date of Membership.
BROWN, J. STANFORD, *E.E.*, [Life Member.]	Consulting Electrical Engineer; Carpenter Steel Co., 1 Broadway and 100 Broadway, New York City; residence, Park Hill, Yonkers, N. Y.	A Sept. 6, 1887 M Nov. 1, 1887
BRUSH, CHAS. F.	Electrical Engineer, 453 The Arcade, Cleveland, O.	A April 15, 1884 M Oct. 21, 1884
BURLEIGH, CHAS. B.	Electrical Engineer, General Electric Co., 180 Summer St., Boston, Mass.	A April 21, 1891 M Feb. 16, 1892
CAHOON, JAS. B.	Electrical Engineer; General Manager, The Elmira Municipal Improvement Co., 313 Columbia St., Elmira, N. Y.	A June 17, 1890 M May 19, 1891
CALLENDER, ROMAINE	Electrician, Ryton-on-Tyne, Eng.	A Sept. 27, 1892 M May 21, 1895
CARHART, HENRY S.	Prof. of Physics, University of Michigan, Ann Arbor, Mich.	A Sept. 25, 1895 M April 22, 1896
CARROLL, LEIGH	Algiers Waterworks and Electric Co., Bank of Commerce Bldg. New Orleans, La.	A Oct. 1, 1889 M Nov. 12, 1889
CARUS-WILSON, CHARLES A.	Professor of Electrical Engineering, McGill University, Montreal, P. Q.	A April 18, 1894 M April 17, 1895
CHAMBERLAIN, J. C.	Electrical Engineer, Morris Heights; residence, 1 West 81st St., New York City.	A Dec. 6, 1887 M Jan. 3, 1888
CHANDLER, PROFESSOR CHARLES F.	Columbia University 41 East 49th St., New York City.	A Jan. 20, 1891 M June 7, 1892
CHASE, HARVEY STUART	Mechanical and Electrical Engineer, 8 Congress St., Boston, Mass.	A Sept. 19, 1894 M Jan. 22, 1896
CHENEY, W. C.	Electrical Engineer, Portland Oregon; Residence, Oregon City, Or.	A Sept. 22, 1891 M Nov. 21, 1894
CHILDS, ARTHUR EDWARDS, *B. Sc. M.E.E.E.*	Manager New England Office, The Electric Storage Battery Co., 89 State Street, Boston, Mass.	A June 20, 1894 M April 17, 1895
CHURCHILL, ARTHUR	British Thomson-Houston Co., 83 Cannon Street, London, Eng.	A April 15, 1890 M Jan. 17, 1893
CLARK, ERNEST P.	Electrical Engineer, B. Altman & Co., 19th St., and 6th Ave., New York City.	A Jan. 8, 1887 M Nov. 1, 1887
CLARKE, CHAS. L.	Electrical Engineer and Patent Expert, 31 Nassau St., New York City.	A April 15, 1884 M Jan. 6, 1885
COLBY, EDWARD A.	Consulting Engineer, Lock Box 113, Newark, N. J.	A April 2, 1889 M May 7, 1889
COLVIN, FRANK R.	Western Electric Co., 57 Bethune St., New York City.	A April 18, 1894 M May 21, 1895
COMSTOCK, LOUIS K.	Electrical Engineer, Western Electric Co., Chicago, Ill.	A Dec. 20, 1893 M Nov. 20, 1895

e.	Address.	Date of Membership.
ERBERT	Electrical Engineer, 5328 Green St., Germantown, Pa.	A July 12, 1887 M Sept. 6, 1887
CE	Engineer, Westinghouse Elec. and Mfg. Co., N. Y. Life Bldg,, Chicago, Ill.	A Sept. 25, 1895 M Mar. 25, 1896
LES L.	Electrical Engineer, Hamilton, O.	A Feb. 7, 1890 M June 27, 1895
D H.	Technical Adviser to the Cowles Smelting and Aluminum Co., 656 Prospect St., Cleveland, O.	A Mar. 5, 1886 M May 7, 1889
Y	New England Electrical Supply Co., 49 Federal St., Boston, Mass.	A May 16, 1893 M Feb. 27, 1895
PH EDWIN	Electrician, C. & P. Telephone Co., 619 Fourteenth St., N. W. Washington, D. C.	A April 18, 1892 M April 18, 1894
CIS BACON ber.]	(*President*) Professor of Electrical Engineering, Columbia University, New York.	A May 24, 1887 M April 2, 1889
WELLINGTON	Electrical Engineer, Room 102, 15 Federal St., Boston; residence, Wellington, Mass.	A Feb. 21, 1894 M Feb. 27, 1895
S R.	Thayer Professor of Physics, and Director of the Rogers Laboratory, Mass. Institute of Technology, Boston, Mass.	A April 15, 1884 M Oct. 21, 1884
Y COOKE, JR.	Electrical Consulting and Constructing Engineer, 39 Cortlandt St., New York City.	A Sept. 19, 1894 M Nov. 18, 1896
E	Dealer in Electrical Supplies, 851 The Rookery, Chicago, Ills.	A June 17, 1890 M May 19, 1891
.	Electrician, The Commercial Cable Co., 20 Broad St., New York.	A Nov. 1, 1887 M Dec. 6, 1887
	Consulting Electrical Engineer and Contractor, Sydney, N. S. W.	A Dec. 9, 1884 M Jan. 6, 1885
CIS G.	Electrical Engineer, Fairhaven and Westville R. R. Co., P. O. Box 394, New Haven, Conn.	A Nov. 12, 1889 M June 20, 1894
REDERIC W.	Consulting Electrical and Mechanical Engineer, 907 Drexel Building, Philadelphia, Pa.	A Sept. 19, 1894 M Nov. 25, 1895
	Cable Engineer and Electrician, Central and South American Telegraph Co , Lima, Peru.	A May 18, 1897 M Oct. 27, 1897
.	Professor of Physics, University of Wisconsin, 523 North Carroll St., Madison, Wis.	A Jan. 7, 1890 M Mar. 18, 1890
S H., *C. E.*,	Consulting and Constructing Engineer, 99 Cedar St., 576 Lexington Ave., New York City, and 308 Walnut St., Philadelphia, Pa.	A Mar. 18, 1890 M June 17, 1890

Name.	Address.	Date of Membership.
DAVIS, MINOR M.	Ass't Electrician, Postal Telegraph-Cable Co., 253 Broadway, New York City.	A April 6, 1886 M May 16, 1893
DAWSON, PHILIP	Associate and Chief Engineer with R. W. Blackwell, 39 Victoria St., Westminster, London, Eng.	A Sept. 25, 1895 M Feb. 17, 1897
DECKER, EDWARD P.	Assistant Chief Engineer, Sprague Electric Co., 20 Broad St., New York City; residence, Van Pelt Manor, N. Y.	A Feb. 26, 1896 M Oct. 27, 1897
DELAFIELD, A. FLOYD, *Ph. D.*	Electrical Engineer, Noroton, Conn.	A May 7, 1889 M Oct. 1, 1889
DELANY, PATRICK BERNARD	Inventor, South Orange N. J.	A April 19, 1884 M Nov. 24, 1891
DICKENSON, SAMUEL S.	Sup't, Commercial Cable Co., Hazel-Hill, Guysborough Co., N. S.	A Mar. 6, 1888 M Oct. 1, 1889
DIEHL, PHILIP	Inventor, Singer Sewing Machine Co., 508 Morris Ave., Elizabeth, N. J.	A April 15, 1884 M Dec. 9, 1884
D'INFREVILLE, GEORGES	Electrical Engineer and Expert, 10 Desbrosses St., New York City.	A Nov. 1, 1887 M Dec. 6, 1887
DION, ALFRED A.	General Supt., The Ottawa Electric Co., 72 Sparks St., Ottawa, Ont.	A Jan. 7, 1890 M Nov. 15, 1893
DOANE, SAMUEL EVERETT	Sup't. Marlborough Electric Machine and Lamp Co., Marlborough, Mass.	A Aug. 6, 1889 M June 27, 1895
DODGE, PROF. OMENZO G.,	U. S. Navy, Navy Dep't, Washington, D. C.	A Sept. 20, 1893 M April 17, 1895
DOIJER, H.	Consulting Electrical Engineer, 8 Choorstraat, Delft, Holland.	A Jan. 7, 1890 M Mar. 18, 1890
DOMMERQUE, FRANZ J.	Chief Draughtsman, Chicago Telephone Co.; residence, 496 N. Robey St., Chicago, Ill.	A Oct. 17, 1894 M Mar. 25, 1896
DONNER, WILLIAM H.	Electrical Eng'g Dept. International Correspondence School, Scranton, Pa.	A Nov. 18, 1890 M Dec. 16, 1890
DOW, ALEX	Manager, Edison Illuminating Co., Detroit, Mich.	A Sept. 20, 1893 M Dec. 18, 1895
DUDLEY, CHARLES B.	Chemist and Scientific Expert, Penn. R. R. Co., 1219 Twelfth Ave., Altoona, Pa.	A Oct. 1, 1889 M Nov. 12, 1889
DUNBAR, F. W.	417 West 23d St., New York City.	A Dec. 21, 1892 M May 16, 1893
DUNCAN, DR. LOUIS	(*Past-President*) Johns Hopkins University, residence, 139 E. North Ave., Baltimore, Md.	A July 12, 1887 M Sept. 6, 1887
DUNN, GANO SILLICK	(*Manager.*) Chief Engineer, Crocker-Wheeler Electric Co., Ampere, E. Orange, N. J.; residence, 223 Central Park, West, New York City.	A April 21, 1891 M June 20, 1894
DUNSTON, ROBT. EDWARD	General Manager, Saratoga Traction Company, Saratoga Springs, N. Y.	A Oct 27, 1891 M Feb. 16, 1892

Name.	Address.	Date of Membership.
Dyer, R. N.	Patent Attorney, 31 Nassau St., New York City.	A July 12, 1887 M Sept. 6, 1887
Edison, Thomas A.	Mechanician and Inventor, Orange, N. J.	A April 15, 1884 M Oct. 21, 1884
Edgar, C. L.	General Manager and Chief Engineer, Edison Elec. Ill'm'g Co., 3 Head Place, Boston, Mass.	A Jan. 22, 1896 M May 19, 1896
Egger, Ernst	Electrical Engineer care of B. Egger & Co , X., Simmeringstr, 187, Vienna, Austria.	A Feb. 21, 1893 M Mar. 21, 1894
Emery, Charles Edward	Consulting Engineer, 915 Bennett Building, cor. Fulton and Nassau Sts., New York City.	A June 26, 1891 M April 19, 1892
Emmet, W. L, R.	Electrical Engineer, General Electric Co., Schenectady, N. Y.	A June 6, 1893 M Jan. 17, 1894
Everest, Augustine R.	Electrical Engineer, General Electric Co., Lynn, Mass.	A May 19, 1891 M Dec. 20, 1893
Farnham, Isaiah H.	Electrical Engineer, N. E. Telephone & Telegraph Co., 125 Milk St., Boston, Mass.	A June 8, 1887 M July 12, 1887
Fessenden, Reginald A.	Professor of Electrical Engineering, Western University of Pennsylvania, Allegheny, Pa.	A Oct. 21, 1890 M Dec. 16, 1890
Field, C. J., *M. E.*	Consulting and Constructing Engineer, 30 Broad Street, New York City.	A June 8, 1887 M Nov. 1, 1887
Field, Henry George	Consulting Electrical Engineer, Field & Hinchman, 1203 Majestic Building, Detroit, Mich.	A April 22, 1896 M Dec. 16, 1896
Field, Stephen D.	Electrical Engineer, Stockbridge, Mass.	A April 15, 1884 M Oct. 21, 1884
Fish, Walter Clark	Manager Lynn Works, General Electric Co., Lynn, Mass.	A June 26, 1891 M Feb. 26, 1896
Fitzmaurice, James S.	Chief Engineer, The Electric Light Branch, 210 George St , Sydney, N. S. W.	A Sept. 20, 1893 M Mar. 21, 1894
Flack, J. Day	Supt. Home Ice Machine Co., 56 Pine St., New York City; residence, 80 Carlton St. East Orange, N. J.	A Dec. 6, 1887 M May 21, 1895
Fortenbaugh, S. B.	Asst. Prof. of Electrical Engineering, University of Wisconsin, Madison, Wis.	A April 17, 1895 M Dec. 16, 1896
Foster, Horatio A.	Electrical Engineer, Room 682, Ellicott Square, Buffalo.	A June 8, 1887 M Sept. 6, 1887
Foster, Samuel L.	Electrical Engineer, Market Street Railway Co. 19 Hobart Bldg.; residence, 3687 24th St., San Francisco, Cal.	A Feb. 26, 1896 M Nov. 18, 1896
Freeman, Dr. Frank L.	Attorney-at-Law, Solicitor of Patents, Electrical Expert, 931 F St., Washington, D. C.	A May 7, 1889 M Sept. 3, 1889

Name.	Address.	Date of Membership.
FREEDMAN, WILLIAM H.	Tutor in Electrical Engineering, School of Mines, Columbia University; residence, 157 W. 119th St., New York City.	A Mar. 18, 1890 M Dec. 18, 1895
GALE, HORACE B.	Consulting and Contracting Electrical and Mechanical Engineer, Natick Mass.	A Nov. 15, 1892 M May 16, 1893
GARDANIER, GEORGE W.	Assis't Electrical Engineer, Western Union Telegraph Co., 195 Broadway, New York City.	A April 18, 1893 M Jan. 22, 1896
GARRATT, ALLAN V.	Chief Engineer, Lombard Waterwheel Governor Co., 61 Hampshire St., Boston, Mass.	A April 2, 1889 M May 7, 1889
GERRY, M. H., JR.	Supt. of Motive Power, The Metropolitan West Side Elevated Railroad Co., 146 Throop St., Chicago, Ill., 3333 Cedar Ave., Minneapolis Minn.	A April 18, 1893 M Oct. 21, 1896
GEYER, DR. WM. E.	Stevens Institute of Technology, Hoboken, N. J.	A June 5, 1888 M Sept. 7, 1888
GHARKY, WILLIAM DAVID	Electrician, Standard Telephone Co., 401 South Juniper St., residence, Hotel Lorraine, Philadelphia, Pa.	A May 21, 1895 M Feb. 26, 1896
GIBBS, LUCIUS T.	Manager and Chief Engineer, Gibbs Electric Co., Holworthy Chambers, 152 Madison Ave., New York City.	A Mar. 25, 1896 M Feb. 17, 1897
GIFFORD, CLARENCE E.	Electrical Engineer, Box, 292, Oil City, Pa.	A May 16, 1893 M Feb. 21, 1894
GOLTZ, WILLIAM	Hathaway Building, Milwaukee, Wis.	A Oct. 27, 1897 M Feb. 23, 1898
GRAY, DR. ELISHA	Electrician and Inventor, Highland Park, Ill.	A Feb. 16, 1892 M May 17, 1892
GREENE, S. DANA	Assistant General Manager, General Electric Co., Schenectady, N. Y.	A Sept. 20, 1893 M April 18, 1894
GUTMANN, LUDWIG	Electrical Engineer, 815 North Jefferson Ave., Peoria, Ill.	A Sept. 14, 1888 M Mar. 21, 1893
HADAWAY, W. S., Jr.	Electric Heating Engineer, 107 Liberty St., New York City.	A Nov. 21, 1894 M Oct. 21, 1896
HALL, CLAYTON C.	Civil Engineer, 810 Park Ave., Baltimore, Md.	A April 15, 1884 M Oct. 21, 1884
HALL, JOHN L.	Crocker & Wheeler Electric 14 South Broad St., Philadelphia, Pa. residence, 715 West 10th St., Wilmington, Del.	A Sept. 22, 1891 M Dec. 20, 1893
HAMBLET, JAMES	Manager Time Service, W. U. Tel. Co., 195 Broadway, P. O. Box 856, NewYork City; residence, 20 Sidney Place, Brooklyn, N. Y.	A Nov. 1, 1887 M Dec. 6, 1887
HAMILTON, GEO. A.	(*Treasurer.*) Electrician, Western Electric Co., 57 Bethune St., New York; residence, 532 Morris Ave., Elizabeth, N. J.	A April 15, 1884 M Oct. 21, 1884

Name.	Address.	Date of Membership.
HAMMER, EDWIN W.	Electrical Engineer, 46 Second Ave., Newark, N. J.	A Nov. 18, 1896 M June 23, 1897
HAMMER, WILLIAM J.	Consulting and Supervising Electrical Engineer, 1305 Havemeyer Bldg, 26 Cortlandt St., New York City.	A June 8, 1887 M July 12, 1887
HARRINGTON, WALTER E.	Electric Railway Engineer, 307 Market St., Camden, N. J.	A Mar. 17, 1891 M May 19, 1896
HARRISON, RUSSELL B.	Pres. and Electrical Engnieer, Terre Haute Electric Railway Co., Terre Haute, Ind.	A Sept. 25, 1895 M April 22, 1896
HARTWELL, ARTHUR	Manager Pittsburg Agency, Westinghouse Electric and Mfg. Co.; residence, 6804 McPherson St., Pittsburg, Pa.	A May 15, 1894 M Nov. 20, 1895
HASKINS, CARYL D.	Electrical Engineer, General Electric Co., 180 Summer St., Boston, Mass.	A Mar, 18, 1890 M June 20, 1894
HASKINS, CHARLES H.	Electrician, 70 Linwood Avenue, Buffalo, N. Y.	A April 15, 1884 M Oct. 21, 1884
HASKINS, CLARK CARYL	Electrical Engineer, 682a West Adams St., Chicago, Ill.	A Sept. 20, 1893 M Mar. 21, 1894
HASSON, W. F. C.	(*Manager.*) Firm of Hasson & Hunt, Consulting and Supervising Mechanical and Electrical Engineers, 310 Pine St., Telephone 5650, San Francisco, Cal.	A Mar. 18, 1890 M May 15, 1894
HAYES, HAMMOND V.	Electrician, American Bell Telephone Co,, 42 Farnsworth St., So. Boston Mass.	A Nov. 12, 1889 M Mar. 18, 1890
HAYES, HARRY E.	Asst. Electrician, American Telegraph and Telephone Co., 153 Cedar St., New York City.	A April 18, 1893 M Dec. 20, 1893
HAYNES, F. T. J.	Divisional Telegraph Engineer, Great Western Railway; residence, Belmont Villa, Cheddon Road, Taunton, Eng.	A Dec. 6, 1886 M Jan. 3, 1887
HEATH, HARRY E.	Electrical Engineer, Windsor, Conn.	A Mar. 21, 1893 M Mar. 25, 1896
HEINRICH, RICHARD O.	Electrical Engineer, The European Weston Electrical Instrument Co., 88 Ritterstrasse, Berlin, Germany.	A Oct. 1, 1889 M Oct. 25, 1892
HENSHAW, FREDERICK V.	79 State St., Brooklyn, N Y.	A Feb. 5, 1889 M Nov. 20, 1895
HERDMAN, FRANK E.	Mechanical and Electrical Engineer, Crane Elevator Co., Winnetka, Ill.	A Dec. 18, 1895 M Oct. 21, 1896
HERING, CARL [Life Member.]	(*Manager.*) Consulting Electrical Engineer, 929 Chestnut St.; residence 124 E. Mt. Pleasant Ave., Philadelphia, Pa.	A Jan. 3, 1888 M June 5, 1888
HERING, HERMANN S.	Associate in Electrical Engineering, Johns Hopkins University, residence, 1809 Park Ave., Baltimore, Md	A April 21, 1891 M April 18, 1893

Name.	Address.	Date of Membership.
HERRICK, CHARLES H.	Superintendent Isolated, Lighting and Power Dep't., Edison Electric Illuminating Co., 3 Head Place, Boston; residence, 22 Herrick St., Winchester, Mass.	A April 21, 1891 M Jan. 17, 1893
HERZOG, F. BENEDICT, *Ph. D.*	President, Herzog Teleseme Co., Townsend Building, Broadway and 25th St., New York City.	A May 24, 1887 M July 12, 1887
HEWITT, CHARLES	Electrical Engineer, Union Traction Co., 820 Dauphin Street, Philadelphia, Pa.	A Sept. 16, 1890 M May 17, 1892
HIBBARD, ANGUS S.	General Manager, Chicago Telephone Co., 203 Washington St., Chicago, Ill.	A Nov. 24, 1891 M Feb. 16, 1892
HIGGINS, EDWARD E.	Editor, *Street Railway Journal*, 26 Cortlandt St., New York City.	A June 8, 1887 M July 12, 1887
HIX, E. RANDOLPH	Hix, Hamilton & Co., Electrical Engineers and Contractors, 41 Wall St., New York City.	A Feb. 21, 1894 M Feb. 27, 1895
HOLMES, FRANKLIN S.	Electrical Engineer, 108 Fulton St., New York City; residence 445a Macon St., Brooklyn, N. Y.	A April 21, 1891 M June 20, 1894
HOUSTON, EDWIN J., *Ph.D.* [Life Member.]	(*Past President.*) Prof of Physics, Franklin Inst., Firm of Houston & Kennelly, Crozer Bldg., 1420 Chestnut St.; residence, 1809 Spring Garden St., Phila., Pa.	A April 15, 1884 M Oct. 21, 1884
HOWELL, JOHN W.	Electrician, 20 Chestnut St., Newark, N. J.	A July 12, 1887 M June 5, 1888
HOWELL, WILSON S.	Lamp Testing Bureau Box, 114, Newark, N. J.; residence, 152 Prospect St., East Orange, N. J.	A Sept. 3, 1889 M Mar. 18, 1890
HUMPHREY, HENRY H.	Consulting Electrical Engineer, Bryan & Humphrey, Turner Bldg. St. Louis, Mo.	A Dec. 16, 1896 M April 28, 1897
HUNTER, RUDOLPH M.	Expert and Counsellor in Patent Causes, 926 Walnut St., Philadelphia, Pa.	A July 13, 1886 M May 17, 1887
HUNTING, FRED S.	Chief Engineer, Engineering Department, Fort Wayne Electric Co., 8 Rockhill St., Fort Wayne, Ind.	A Nov. 15, 1892 M May 16, 1893
HUTCHINSON, DR. CARY T.	(*Manager.*) Electrical Engineer, 253 Broadway, New York City.	A Feb. 7, 1890 M Dec. 16, 1890
HYDE, JEROME W.	Ass't Treasurer, The Springfield Steam Power Co., Wason Bldg. Springfield, Mass.	A June 8, 1887 M Nov. 1, 1887
INRIG, ALEC GAVAN	Globe Electrical Co., 44 White Post Lane, Victoria Park, London, Eng.	A Jan. 19, 1892 M May 17, 1892
IVES, EDWARD B.	Chief Engineer, Raritan Construction Co., 153 Bullitt Bldg., Philadelphia, Pa.	A April 2, 1889 M May 15, 1894
JACKSON, DUGALD C.	(*Vice-President.*) Professor of Electrical Engineering, University of Wisconsin, Madison, Wis.	A May 3, 1887 M June 17, 1890

Name.	Address.	Date of Membership.
JACKSON, FRANCIS E.	Aylsworth & Jackson, Incandescent Filament Manufacturers, 128 Essex Ave., Orange; residence, 61 South Grove St., East Orange, N. J.	A Jan. 3, 1888 M June 17, 1890
JACKSON, HENRY	Telegraph Supt. and Engineer, The Lancashire & Yorkshire Railway Co., Horwich, Bolton-le Moors, Lancashire, England.	A Mar. 21, 1894 M Dec. 19, 1894
JACKSON, JOHN PRICE	Professor of Electrical Engineering, Penn. State College, State College, Pa.	A Sept. 27, 1892 M Jan. 17, 1894
JANNUS, FRANKLAND	Attorney-at-Law, Solicitor of Patents, 1022 Havemeyer Building, New York City.	A Nov. 12, 1889 M Mar. 18, 1890
JEHL, FRANCIS	Lichtenauergasse 8, Brünn, Moravia, Austria.	A June 27, 1895 M Jan. 22, 1896
JENKS, W. J.	Secretary, Board of Patent Control, 120 Broadway, New York City.	A June 8, 1887 M Nov. 1, 1887
JOHNSTON, A. LANGSTAFF	Chief Engineer, Richmond Traction Co., 1112 E. Main St., Richmond, Va.	A April 21, 1891 M April 18, 1894
JONES, FRANCIS WILEY [Life Member.]	Assistant Gen'l-Manager and Electrician, Postal Telegraph-Cable Co., 253 Broadway, New York City.	A April 15, 1884 M Oct. 21, 1884
KEITH, DR. NATHANIEL S.	Care R. W. Pope, Sec'y. 26 Cortlandt St., New York, N. Y.	A April 15, 1884 M Jan. 17, 1894
KINSMAN, FRANK E.	Electrical Engineer, 66 Broadway, New York City; residence, 836 Sherman Ave., Plainfield, N. J.	A Sept 27, 1892 M May 16, 1893
KNOWLES, EDWARD R. *E. E., C. E.*	150 Nassau Street, New York City; residence, 82 Cambridge Place, Brooklyn, N. Y.	A June 8, 1887 M July 12, 1887
KNUDSON, A. A.	Electrical Engineer, 66 Broadway, New York City; residence, 127 Prospect Place, Rutherford, N. J.	A Dec. 6, 1887 M Jan. 3, 1888
LANGE, PHILIP A.	Superintendent Westinghouse Electric and Manufacturing Co., East Pittsburg, Pa.	A Mar. 6, 1888 M June 5, 1888
LANGTON, JOHN	Electrical Engineer, Canada Life Building, Toronto, Ont., and 72 Trinity Place, New York, N. Y.	A Mar. 6, 1888 M June 5, 1888
LA ROCHE, FRED. A.	President and General Manager, Ideal Electric Corporation, 652–660 Hudson Street; residence, 28 W. 25th St., New York.	A Sept. 19, 1894 M Nov. 20, 1895
LATTIG, J. W.	Electrical Engineer, Supt. of Telegraph and Electrical Apparatus, Lehigh Valley R. R. Co., So. Bethlehem, Pa.; residence, 335 Broad St., West Bethlehem, Pa.	A June 8, 1887 M July 12, 1887

Name.	Address.	Date of Membership.
LAWSON, A. J.	Electrical Engineer, The County of London and Brush Provincial Electric Lighting Co., Ltd., 49 Queen Victoria St., London, Eng.	A Mar. 18, 1890 M June 17, 1890
LEMP, HERMANN, JR.	Electrician, 186 Allen Avenue, Lynn, Mass.	A April 2, 1889 M Feb. 21, 1893
LEONARD, H. WARD	Electrical Engineer, Pres't. Ward Leonard Electric Co., Bronxville, N Y.; residence, 606 W. 114th St., New York City.	A July 12, 1887 M Sept. 6, 1887
LESLIE, EDWARD ANDREW	Vice-President and Manager, Manhattan Electric Light Co., Ltd., New York City; residence, 343 Hancock St., Brooklyn, N. Y.	A Jan. 16, 1895 M Feb. 17, 1897
LEVIS, MINFORD	Superintendent and Electrical Engineer, Novelty Electric Co., 54 North 4th St., Philadelphia, Pa.	A Feb. 21, 1893 M June 23, 1897
LIEB, JOHN W., JR.	(*Manager.*) General Mgr., Edison Electric Ill. Co.; Residence, 166 West 97th St., New York City.	A Sept. 6, 1887 M Nov. 1, 1887
LIGHTHIPE, JAMES A.	District Engineer, General Electric Co., 15 First St., San Francisco, Cal.	A Feb. 21, 1894 M April 17, 1895
LLOYD, HERBERT	General Manager, Electrical Engineer and Chemist, The Electric Storage Battery Co., Drexel Bldg., Philadelphia, Pa.	A June 20, 1894 M May 21, 1895
LLOYD, JOHN E.	Resident Engineer, South African Tramways Co., 93 Main St., Port Elizabeth, S. Africa.	A Jan. 22, 1896 M Mar. 25, 1896
LLOYD, ROBERT MCA.	Electrician, 22 Broad St.; residence, 1 West 39th St., New York City.	A Oct. 21, 1890 M Nov. 15, 1893
LOCKWOOD, THOMAS D., *F. I. Inst.* [Life Member.]	Electrical Engineer, and Advisory Electrician, P.O. Drawer 2, Boston, Mass.	A April 15, 1884 M Oct. 21, 1884
LOOMIS, OSBORN P.	Electrical and Consulting Engineer, Depew, N. Y.	A Sept. 16, 1890 M Dec. 16, 1896
LORRAIN, JAMES GRIEVE	Norfolk House, Norfolk St., London, W. C., England.	A May 16, 1891 M May 15, 1894
LOVEJOY, J. R.	General Manager, Supply Dept., General Electric Co., Schenectady, N. Y.	A April 21, 1891 M Feb. 21, 1894
MACFARLANE, ALEXANDER, *D. Sc., LL.D.*	(*Manager.*) Professor in Electrical Engineering, Lehigh University, South Bethlehem, Pa.	A Jan. 19, 1892 M May 17, 1892
MAILLOUX, C. O.	Consulting Electrical Engineer, 150 Nassau St., Telephone 3985 Cortlandt, New York City.	A April 15, 1884 M Oct. 21, 1884
MANSFIELD, ARTHUR NEWHALL	Assistant Electrician, American Telephone and Telegraph Co., 153 Cedar St., New York City.	A Dec. 20, 1893 M June 20, 1894

Name.	Address.	Date of Membership.
MARKS, LOUIS B., *M. M. E.*	President, Marks Enclosed Arc Light Co., 689 Broadway; residence, 51 East 67th St., New York City.	A May 20, 1890 M Jan. 16, 1895
MARKS, WILLIAM DENNIS, *Ph.B. C. E.*	President, The American Electric Meter Co., 1014 Betz Building, Philadelphia, Pa.	A Feb. 7, 1888 M May 1. 1888
MARSHALL, J. T.	Metuchen, N. J.	A Oct. 1, 1889 M Nov. 12, 1889
MARTIN, JULIUS	Electrician, 16 Oak St., Newark, N. J., Master Electrician, Equipment Dept., New York Navy Yard.	A Oct. 21, 1890 M Nov. 20, 1895
MARVIN, HARRY N.	Electrical Engineer and Manager, Marvin Electric Drill Co., Canastota, N. Y.	A April 19, 1892 M Jan. 17, 1893
MAVER, WILLIAM, JR.	Electrical Expert and Consulting Electrical Eng'r, 27 Thames St., New York City; residence, 227 Arlington Ave. Jersey City, N. J.	A July 12, 1887 M April 21, 1891
MAYER, GEORGE M.	Enterprise Block, 5th Floor, 79 Fifth Ave., Chicago, Ill.	A Dec. 16, 1890 M June 20, 1894
MAYNARD, GEO. C.	Electrical Engineer, 800 H. St., N. W., Washington, D. C.	A April 15, 1884 M Dec. 9, 1888
MCCAY, H. KENT	Electrical Engineer and Contractor, 106 E. German St., Baltimore, Md.	A Sept. 16, 1890 M May 19, 1891
MCCLUER, C. E.	Superintendent, First District, So. Bell Telephone and Telegraph Co., P. O. Box 32. Richmond, Va.	A Mar. 21, 1893 M Jan. 17, 1894
MCCROSKY, JAMES W.	Chief Engineer, La Capital Tramway Co. and Compaina de Luz y Fuerza Motriz de Cordoba, Reconquista 20, Buenos Aires, Argentina.	A Dec. 20, 1893 M Dec. 16, 1896
MCCROSSAN, J. A.	Manager and Electrician, Citizens' Telephone and Electric Co., Rat Portage, Ont.	A Oct. 18, 1893 M Dec. 18, 1895
MCMEEN, SAMUEL G.	Engineer, Central Union Telephone Co., 1306 Ashland Block, Chicago. Ill.	A Dec. 18, 1895 M Dec. 16, 1896
MERSHON, RALPH D.	Chief Engineer, Colorado Electric Power Co., Colorado Springs, Col.	A Mar. 20, 1895 M Jan. 22, 1896
MILLIS, JOHN	Captain of Engineers U. S. A., The Lighthouse Board, Washington, D. C.	A July 7, 1884 M Mar. 3, 1885
MITCHELL, JAMES	Constructing Engineer and Agent, General Electric Co., Caixa do Correio No. 954, Rio de Janeiro, Brazil.	A Sept. 25, 1895 M Mar. 25, 1896
MIX, EDGAR W.	Electrician, 12 Boulevard des Invalides, Paris, France.	A Sept. 3, 1889 M Mar. 20, 1895
MOLERA, E. J.	Civil Engineer, 606 Clay St., San Francisco, Cal.	A Jan. 16, 1892 M June 7, 1892

Name.	Address.	Date of Membership.
MOORE, D. MCFARLAN	Inventor, Moore Electrical Co., 52 Lawrence St., Newark, N. J.	A Dec. 20, 1893 M June 20, 1894
MORROW, JOHN THOMAS	Supt. Electrolytic Plant, Boston and Montana Consolidated Copper and Silver Mining Co., Great Falls, Mont.	A Dec. 21, 1892 M April 18, 1894
NEILER, SAMUEL G.	Ass't Electrical Engineer, Pierce & Richardson, 1409 Manhattan Building, Chicago, Ill.	A April 18, 1894 M Dec. 18, 1895
NICHOLS, DR. EDWARD L.	Professor of Physics, Cornell University, Ithaca, N. Y.	A Oct. 4, 1887 M Dec. 6, 1887
NICHOLS, GEO P.	Partner, Geo. P. Nichols & Bro., Elec. Engineers and Contractors, 1036 Monadnock Bldg., Chicago, Ill.	A Jan. 22, 1896 M Nov. 18, 1896
NOLL, AUGUSTUS	Contracting Electrical Engineer, 8 East 17th St., Telephone, 62, 18th; New York City.	A Sept. 27, 1892 M April 18, 1893
NUNN, PAUL N.	Consulting Engineer, San Miguel Cons. Gold Mining Co., Telluride, Colo.	A April 17, 1895 M Feb. 26, 1895
O'CONNELL, JOSEPH J.	Telephone Engineer, Chicago Telephone Co., Residence, 76 Eugene St., Chicago, Ill.	A Oct. 17, 1894 M Nov. 20, 1895
O'DEA, MICHAEL TORPEY	Professor of Applied Electricity, University of Notre Dame, Notre Dame, Ind.	A June 8, 1887 M Mar 25, 1896
OUDIN, MAURICE A.	Electrical Engineer, General Electric Co., Schenectady, N. Y.	A June 20, 1894 M Nov. 20, 1895
OWENS, ROBERT BOWIE	Professor of Electrical Engineering, University of Nebraska, Lincoln, Neb.	A June 17, 1890 M Dec. 15, 1897
PAINE, F. B. H.	Westinghouse Electric and Mfg. Co., 328 Exchange Building, Boston, Mass.	A Dec. 16, 1890 M Nov. 25, 1891
PAINE, SIDNEY B.	General Electric Co., 180 Summer St., Boston, Mass.	A June 8, 1887 M Nov. 1, 1887
PARKER, LEE HAMILTON	Ass't Engineer, Railway Dept., General Electric Co., Schenectady, N. Y.	A Aug. 5, 1895 M Dec. 16, 1896
PARKS, C. WELLMAN	Civil Engineer, U. S. N., Norfolk Navy Yard, Va.	A July 12, 1887 M May 1, 1888
PARSHALL, HORACE FIELD	Electrical Engineer, British Thomson-Houston, Ltd., 38 Parliament St., Westminster, London, Eng.	A Sept. 7, 1888 M Mar. 18, 1890
PATTISON, FRANK A.	Firm of Pattison Bros, Consulting and Constructing Electrical Engineers, 136 Liberty St., New York City.	A Sept. 22, 1891 M Dec. 16, 1891
PEARSON, F. S.	Engineer, Room 841, 621 Broadway, New York City.	A Oct. 25, 1892 M Feb. 21, 1893
PEROT, L. KNOWLES	Vice-President and Manager, Schuylkill Valley Illuminating Co., Phœnixville, Pa.	A Mar. 15, 1892 M Dec. 18, 1895

Name.	Address.	Date of Membership.
PERRINE, FREDERIC A. C., *D. Sc.*	Professor of Electrical Engineering, Leland Stanford, Jr., University, Palo Alto, Cal.	A Sept. 16, 1890 M Dec. 16, 1890
PERRY, NELSON W., *E. M.*,	Engineer; residence, Brighton Heights, Staten Island, N. Y.	A May 17, 1892 M Mar. 21, 1893
PICKERNELL, F. A.	(*Manager.*) Chief Engineer, Amer. Tel. & Tel.Co., 153 Cedar St., New York City.	A Feb. 7, 1890 M Mar. 18, 1890
PIERCE, RICHARD H.	Pierce & Richardson, Electrical Engineers, 1409 and 1410 Manhattan Bldg., Chicago; residence, 5434 Monroe Ave., Hyde Park, Ill.	A April 18, 1893 M Dec. 20, 1893
PIKE, CLAYTON W., *B.S.*	Electrical Engineer, Falkenau Engineering Co., 711 Reading Terminal, Philadelphia, Pa.	A Dec. 16, 1891 M Oct. 25, 1892
PORTER, JOSEPH F.	Manager, Alton Railway and Illuminating Co., Alton, Ill.	A Sept. 6, 1887 M Nov. 1, 1887
POTTER, WM. BANCROFT,	Engineer Railway Dept., General Electric Co., Schenectady, N. Y.	A Jan. 22, 1896 M Mar. 25, 1896
POWELL, WILLIAM H.	[Address unknown.]	A June 17, 1890 M Mar. 20, 1893
PRATT, ROBERT J.	Greenbush, N. Y.	A July 12, 1887 M Sept. 6, 1887
PUFFER, WM. L.	(*Manager.*) Assistant Professor of Electrical Engineering, Mass. Institute of Technology, Boston; residence, West Newton, Mass.	A Dec. 20, 1893 M April 17, 1895
RAE, FRANK B.	Electrical Engineer, 1109 Fort Dearborn Bldg., 134 Monroe St., Chicago, Ill.	A April 15, 1884 M Oct. 25, 1892
REBER, SAMUEL	Lieut. Signal Corps, U. S. Army, Headquarters Dept. of Texas, San Antonio, Tex.	A Sept. 20, 1893 M Jan. 22, 1896
RECKENZAUN, FREDERICK,	Electrical Engineer, 44 Pine St., New York City.	A Mar. 6, 1888 M June 5, 1888
REIST, HENRY G.	Designing Engineer, General Electric Co., 5 South Church St., Schenectady, N. Y.	A June 17, 1890 M Dec, 19, 1894
RICE, CALVIN WINSOR	Electrician, Kings County Electric Light and Power Co., Box 774, Brooklyn, N. Y.	A Jan. 20, 1897 M April 28, 1897
RICE, E. WILBUR, JR.	Technical Director, The General Electric Co., Schenectady, N. Y.	A Dec. 6, 1887 M Jan. 3, 1888
RIES, ELIAS E.	Electrical Engineer and Inventor, 1031 Temple Court; residence, 4 W. 115th St., New York City.	A July 12, 1887 M Sept. 6, 1887
RIKER, ANDREW L. [Life Member.]	Electrical Engineer, The Riker Electric Motor Co, 45 York St., Brooklyn; residence, Stamford, Conn.	A Nov. 1, 1887 M Dec. 18, 1895

Name.	Address.	Date of Membership.
ROBB, WM. LISPENARD	Professor of Physics, Trinity College, Hartford, Conn.	A Dec. 16, 1891 M Mar. 15, 1892
ROBERTS, E. P.	E. P. Roberts & Co., Electrical and Mechanical Engineers, Brainard Block, Telephone 2656, Cleveland, O.	A Jan. 6, 1885 M Feb. 3, 1885
RODGERS, HOWARD S.	Electrical Engineer, care General Electric Co., 264 W. 4th Street, Cincinnati, O.	A Sept. 27, 1892 M May 16, 1893
ROHRER, ALBERT L.	Electrical Engineer, with General Electric Co., Schenectady, N. Y.	A Nov. 1, 1887 M May 1, 1888
ROLLER, JOHN E.	Lieut. U. S. N., in charge of Inspection and Installation, U. S. Navy Yard, New York; residence, Cranford, N. J.	A Sept. 19, 1894 M May 19, 1896
ROBB, RUSSELL	With Stone & Webster, 4 P. O. Square, Boston, Mass.	A Oct. 18, 1893 M May 21, 1895
ROSS, NORMAN N.	Electrical Engineer, The Royal Electric Co., Montreal, Can.	A Sept. 20, 1893 M Nov. 21, 1894
ROSS, ROBERT A.	Mechanical and Electrical Consulting Engineer, 17 St. John St., Montreal, P. Q.	A Sept. 27, 1892 M April 18, 1893
ROUQUETTE, WILLIAM F. B.	Proprietor, Rouquette & Co., 47 Dey St., New York City.	A Mar. 21, 1894 M Dec. 19, 1894
RYAN, HARRIS, J.	(*Vice-President.*) Professor of Electrical Engineering, Cornell University, Ithaca, N. Y.	A Oct. 4, 1887 M April 17, 1895
SACHS, JOSEPH	Devising and Consulting Electrical Engineer, 32 Nassau St., New York City.	A Mar. 15, 1892 M Dec. 15, 1897
SALOMONS, *Sir* DAVID LIONEL, *Bart. M. A.*, [Life Member]	Engineer and Barrister, Broomhill, Tunbridge Wells, Kent, and 49 Grosvenor St., London, W. England.	A Feb. 7, 1888 M May 1, 1888
SAMPSON, F. D.	Manager, Charlotte Electric Light and Power Co., Charlotte, N. C.	A Aug. 5, 1896 M Oct. 27, 1897
SANDS, H. S.	Consulting and Constructing Electrical Engineer, Peabody Building, Wheeling, W. Va.	A Feb. 21, 1893 M Nov. 21, 1894
SARGENT, WILLIAM D.	General Manager, N. Y. & N. J. Tel. Co., 16 Smith St., Brooklyn, N. Y.	A April 15, 1884 M Feb. 21, 1894
SCHEFFLER, FRED. A.	General Factory Manager, Sprague Electric Co., Bloomfield, N. J.; residence, Passaic, N. J.	A May 16, 1893 M Jan. 26, 1896
SCHMID, ALBERT	Superintendent, Westinghouse Electric and Mfg. Co., Pittsburg, Pa.	A Oct. 21, 1890 M April 17, 1895
SCHOEN, A. M.	Electrician, South Eastern Tariff Association, Norcross Building, Atlanta, Ga.	A Sept. 20, 1893 M Dec. 16, 1896
SCOTT, CHARLES F.	(*Manager.*) Chief Electrician, Westinghouse Electric and Mfg. Co., Pittsburg, Pa.	A April 19, 1892 M Jan. 17, 1893

Name.	Address.	Date of Membership.
Sever, George F.	Instructor in Electrical Engineering, Columbia University, New York City.	A Jan. 17, 1894 M May 19, 1896
Shaw, Edwin C.	Manager, Akron General Electric Co., Akron, O.	A May 17. 1892 M Feb. 27, 1895
Shea, Daniel W.	Professor of Physics, Catholic University of America, Washington, D. C.	A Dec. 20, 1893 M June 20, 1894
Sheble, Franklin	Electrical Engineer, 1026 Filbert St., Philadelphia, Pa.	A Oct. 21, 1890 M Dec. 18, 1895
Sheldon, Samuel, *A. M.*, *Ph.D.*	Professor of Physics and Electrical Engineering, Polytechnic Institute, 198½ Schermerhorn, St., Brooklyn, N. Y.	A Dec. 16, 1890 M Oct. 27, 1891
Shepardson, George D.	Professor of Electrical Engineering, University of Minnesota, Minneapolis, Minn.	A April 21, 1891 M Jan. 22, 1896
Sinclair, H. A.	Electrical Engineer, The Tucker Electric Co., 950 Bedford Ave., Brooklyn, N. Y.	A June 17, 1890 M Feb. 26, 1896
Smith, Frank Stuart	Supt. Lamp Factory, Sawyer-Man Electric Co., Pittsburg, Pa.	A Sept. 27, 1892 M April 18, 1893
Smith, Jesse M.	Expert in Patent Causes, Consulting Electrical and Mechanical Engineer, 36 Moffat Block, Detroit, Mich.	A April 15, 1884 M June 26, 1891
Smith, T. Carpenter	Mechanical and Electrical Engineer, 212 Drexel Building, Philadelphia, Pa.	A Oct. 27, 1891 M Dec. 16, 1891
Spaulding, Hollon C.	Electrical Engineer, Manager, N. E. Office, Manhattan General Construction Co., 611 John Hancock Bldg., Boston, Mass.	A April 21, 1891 M June 20, 1894
Sperry, Elmer A.	Electrical Engineer, Sperry Electric Railway Co., Mason and Belden Sts., Cleveland, O.	A April 19, 1892 M Feb. 21, 1893
Sprague, Frank J.	(*Past-President.*) Vice-Prest. Sprague Electric Elevator Co.. Postal Telegraph Bldg., 22 Broad St., and 182 West End Ave., New York City.	A May 24, 1887 M Feb. 17, 1897
Standford, William	Asst. Supt. Telegraphs, Colonial Govt., Cape Town, Cape of Good Hope, Africa.	A Oct. 4, 1887 M Dec. 6, 1887
Stearns, Charles K. *E.E.*	Room 15, 116 Bedford Street, and 85 Westland Avenue, Boston, Mass.	A Aug. 6, 1889 M May 16, 1893
Stearns, Joel W., Jr.	Treasurer. Mountain Electric Co., Box 1545, Denver, Col.	A June 20, 1894 M Nov. 20, 1895
Stebbins, Theodore	Engineer of Committee on Local Companies, General Electric Co., Schenectady, N. Y.	A July 9, 1889 M June 17, 1890

Name.	Address.	Date of Membership.
STEINMETZ, CHARLES P.	(*Vice-President.*) Electrician, General Electric Co., Schenectady, N. Y.	A Mar. 18, 1890 M April 21, 1891
STEPHENS, GEORGE	General Supt., Canadian General Electric Co., Ltd., Peterboro, Ont.	A June 20, 1894 M Dec. 18, 1895
STIERINGER, LUTHER	Electrical Expert, Beard Building, 120 Liberty St., New York City.	A June 8, 1887 M Nov. 1, 1887
STILLWELL, LEWIS B.	(*Manager.*) Electrical Director, Niagara Falls Power Company, and the Cataract Construction Co., Niagara Falls, N. Y.	A April 19, 1892 M Nov. 15, 1892
STOTT, HENRY G.	Electrical Engineer, Buffalo Gen'l Electric Co., Buffalo, N. Y.	A Sept. 25, 1895 M April 22, 1896
TAINTOR, GILES	Division Sup't. Western Division New England Telephone and Telegraph Co., Springfield, Mass.	A June 26, 1891 M Dec. 16, 1891
TALTAVALL, THOS. R.	Editor, *Electrical World*, 253 Broadway, New York City.	A Jan. 20, 1891 M Oct. 27, 1891
TERRY, CHARLES A.	Lawyer, Westinghouse Electric and Mfg. Co., 120 Broadway, New York City.	A April 5, 1887 M May 17, 1887
THOMAS, BENJAMIN F., *Ph. D.*	Professor of Physics, Ohio State University, Columbus, O.	A June 7, 1892 M Nov. 15, 1892
THOMSON, PROF. ELIHU	(*Past President*). Electrician, General Electric, and Thomson Electric Welding Companies, Lynn, Mass.	A April 15, 1884 M April 21, 1891
THOMPSON, EDWARD P.	Consulting Electrician and Patent Attorney in Electrical Cases, 83 Fulton St., New York City.	A April 15, 1884 M Dec. 3, 1889
THURNAUER, ERNST	Manager, Thomson-Houston International Elec. Co., 27 Rue de Londres, Paris, France.	A Oct. 14, 1887 M Dec. 6, 1887
TISCHENDOERFER, F. W.	Electrical Engineer, Schückert & Co., Nuremberg, Germany.	A April 19, 1892 M Nov. 21, 1894
TRAFFORD, EDWARD W.	Electrical Engineer, Richmond Railway and Electric Co., Foot of 7th St., Richmond, Va.	A Feb. 21, 1894 M Dec. 19, 1894
TURNER, WILLIAM S.	Consulting and Constructing Electrical and Mechanical Engineer, 1 Nassau St., New York City.	A Dec. 7, 1886 M Oct. 2, 1888
UEBELACKER, CHAS. F.	Electrical Engineer, Consolidated Traction Co., 30 North 11th St., Newark, N. J.	A Feb. 7, 1890 M Nov. 15, 1893
UHLENHAUT, FRITZ, JR.	Philadelphia Traction Co., 4101 Haverford St., Philadelphia, Pa.	A May 7, 1889 M Dec. 19, 1894
UPTON, FRANCIS R	Edison Laboratory, Orange, N. J.	A May 17, 1887 M Mar. 15, 1892
VAIL, J. H	Engineer-in-Chief, Penn. Heat, Light and Power Co., and Edison Electric Light Co., 909 Walnut St., Philadelphia, Pa.	A June 8, 1887 M Nov. 1, 1887

Name.	Address.	Date of Membership.
VANSIZE, WILLIAM B.	Solicitor of Patents and Expert, 253 Broadway; residence, Hotel Grenoble, New York City.	A April 15, 1884 M Oct, 21, 1884
VAN TRUMP, C. REGINALD	Engineer and Manager, Wilmington City Electric Co., Wilmington, Del.	A Feb. 5, 1886 M Feb. 21, 1894
WADDELL, MONTGOMERY	Consulting Engineer, 72 Trinity Place, New York City.	A Feb. 7, 1888 M May 1, 1888
WAIT, HENRY H.	Assistant Electrical Engineer, Western Electric Co., 4919 Madison Ave., Chicago, Ill.	A Sept. 20, 1893 M June 20, 1894
WALDO, DR. LEONARD	Electrical Engineer, Secretary, The Waldo Foundry, 57 Coleman St., Bridgeport, Conn.	A June 5, 1888 M Dec. 4, 1888
WALKER, SYDNEY F.	Electrical Engineer, 195 Severn Road, Cardiff, Wales.	A June 2, 1885 M May 17, 1887
WARING, JOHN	Ovid, N. Y.	A Dec. 16, 1890 M April 17, 1895
WARNER, ERNEST P.	Electrical Engineer, Western Electric Co.; residence, 402 Belden Ave., Chicago, Ill.	A Sept. 20, 1893 M June 20, 1894
WATERMAN, F. N.	Electrical Engineer, Westinghouse Electric and Mfg. Co., 120 Broadway, New York City.	A Feb. 21, 1893 M June 20, 1894
WEAVER, W. D.	Editor *American Electrician*, 7 West 26th Street, New York City.	A May 17, 1887 M May 17, 1887
WEBB, HERBERT LAWS	(*Manager*) 18 Cortlandt St.; residence, 253 West 42d St., New York City.	A Oct. 21, 1890 M Dec. 16, 1890
WEEKS, EDWIN R.	706 Wall St., Kansas City, Mo.	A Sept. 6, 1887 M Nov. 1, 1887
WELLER, HARRY W.	Electrical Engineer, Room 206, Equitable Building, Boston, Mass.	A Oct. 21, 1890 M Nov. 24, 1891
WESTON, EDWARD	(*Past President.*) Vice-President. Weston Electrical Instrument Co, 120 William St., and 645 High St., Newark, N. J.	A April 15, 1884 M Oct. 21, 1884
WETZLER, JOSEPH	Editor *The Electrical Engineer*, 120 Liberty St., New York City.	A April 15, 1884 M Dec. 9, 1884
WHARTON, CHAS. J.	82 Bond St., London, Eng,	A Jan. 3, 1888 M May 1, 1888
WHEELER, SCHUYLER SKAATS, Sc. [Life Member.]	President, Crocker-Wheeler Electric Co., 39 Cortlandt St., N. Y., and Ampere, N. J.; residence, 4 West 33d St., New York City.	A June 2, 1885 M Sept. 1, 1885
WHITE-FRASER, GEO.	*Mem. Can. Soc. C. E.*; 18 Imperial Loan Building, Toronto, Ont.	A Sept. 22, 1891 M Dec. 18, 1895
WIENER, ALFRED E.	Electrical and Mechanical Engineer; residence, 208 Liberty St., Schenectady, N. Y.	A May 16, 1893 M May 15, 1894
WILCOX, NORMAN T.	Sup't Chattanooga Light and Power Co., Chattanooga, Tenn.	A May 21, 1895 M Jan. 22, 1896

Name.	Address.	Date of Membership.
WILKES, GILBERT	Consulting Electrical Engineer, 1112 Union Trust Building, Detroit, Mich.	A Jan. 7, 1890 M Mar. 18, 1890
WILLYOUNG, ELMER G.	E. G. Willyoung & Co., Scientific Instruments and Apparatus, 938 Market St., Philadelphia.	A Nov. 24, 1891 M Dec. 20, 1893
WILSON, CHARLES H.	General Manager, Southern Bell Telephone Co., 26 Cortlandt St., New York City.	A Nov. 24, 1891 M Feb. 16, 1892
WILSON, FREMONT	Electrician, 66 Maiden Lane, (Telephone, 1651 Cortlandt) and 2153 Seventh Ave., New York City.	A Mar. 6, 1888 M June 5, 1888
WILSON, HARRY C.	Supt. of P. O. Telegraph with the Government, Kingston, Jamaica, West Indies.	A Jan. 19, 1891 M June 7, 1892
WINCHESTER, A. E.	Consulting Engineer and Designer of Electric Systems, South Norwalk, Conn.	A June 8, 1887 M Nov. 1, 1887
WINSLOW, GEORGE HERBERT	Consulting Electrical Engineer, 82 & 83 Schmidt Building, 339 Fifth Ave., Pittsburgh, Pa.	A April 17, 1895 M Feb. 26, 1896
WIRT, CHARLES	Consulting Engineer, 1028 Filbert St., Philadelphia, Pa.	A Sept. 8, 1888 M June 20, 1894
WOLCOTT, TOWNSEND	Electrician, 455 Bowling Green Building, New York City.	A Mar. 6, 1888 M Dec. 16, 1890
WOLVERTON, B. C.	Electrician, N. Y. & Pa. Telephone and Telegraph Co., Elmira, N. Y.	A Mar. 18, 1890 M Feb. 21, 1895
WRIGHT, PETER	General Superintendent, People's Electric Light and Power Co., 36 Mechanic St., Newark, N. J.	A May 16, 1889 M Jan. 16, 1895
WURTS, ALEXANDER JAY	Westinghouse Electric & Mfg. Co., Pittsburg, Pa.	A April 19, 1892 M Nov. 15, 1892
YOUNG, C. GRIFFITH	Electrical Engineer, White-Crosby Co., 706 Equitable Building., Baltimore, Md.	A Jan. 3, 1889 M April 21, 1891

Members, - - - 351.

ASSOCIATE MEMBERS.

Name.	Address.	Date of Election.
ABBOTT, HENRY	President, Calculagraph Co., 2 Maiden Lane, N. Y.; residence, 32 So. Clinton St., East Orange, N. J.	Apr. 28, 1897
ABELLA, JUAN	Director General of Public Lighting, Buenos Aires; residence, 691 Calle Bolivar, Buenos Aires, Argentine Republic.	Aug. 5, 1896
ADAE, CHAS. FLAMEN	Room 24, 111 Broadway, P. O. Box, 2809; New York City	Dec. 16, 1896
ADAMS, COMFORT A., JR.	Assistant Professor of Electrical Engineering, Harvard University, 13 Farrar St., Cambridge, Mass.	Jan. 17, 1894
ADAMSON, DANIEL	Manager Joseph Adamson & Co., Hyde, Cheshire, England.	Feb. 26, 1896
AGNEW, CORNELIUS R.	Electrical Engineer, 150 Nassau St., 23 West 39th St., New York City.	Mar. 21, 1894
ALBANESE, G. SACCO	Electrical Expert, Compagnie Francaise Thomson-Houston, Mustapha, Algeria.	Sept. 20, 1893
ALBERT, HENRY	Electrical Engineer, 815 Main St., Jacksonville, Fla.	Feb. 21, 1893
ALDEN, JAMES S.	Assistant Manager, with L. H. Alden, 486 River Drive, Passaic, N. J.	May 19, 1891
ALDRICH, WILLIAM S.	Professor of Mechanical Engineering and Director Mechanical Arts, West Virginia University, P. O. Box 256, Morgantown, W. Va.	Mar. 15, 1892
ALEXANDER, HARRY	Electrical Engineer, General Manager and Vice Prest. Alexander-Chamberlain Electric Co., 56 West 22d St., and 348 W. 145th St., New York City.	April 21, 1891
ANDERSON, HENRY S.	General Manager and Electrician, United Electric Light Co., Springfield, Mass.	Jan. 16, 1895
ANDREWS, WILLIAM, C.	Electrical Engineer, 26 South Aurora St., Ithaca, N. Y.	May 21, 1895
ANSON, FRANKLIN ROBERT	Receiver, Salem Consolidated Street Railway Co., Salem, Ore.	Feb. 27, 1895
ANTHONY, WATSON G.	Electrician, 32½ Webster St., Newark, N. J.	Feb. 24, 1891
APPLEYARD, ARTHUR E.	Manager and Engineer, Natick Gas and Electric Co., Natick, Mass.	Aug. 5, 1896
ARCHBOLD, WM. K.	Westinghouse Electric and Mfg. Co. 120 Broadway, New York City.	June 20, 1894
ARCHER, GEO. F.	Electrical Engineer, 31 Burling Slip, New York City.	Nov. 21, 1894
ARMSTRONG, CHAS. G.	Electrical Expert, 1306 Great Northern Hotel Building, Chicago, Ill.	Sept. 27, 1892
ASHLEY, FRANK M.	Master Mechanic, Ashley Engineering Works, 69 Beekman St., New York.	Nov. 21, 1894

Name.	Address.	Date of Election.
Atkins, Harold B.	Engineer, A. K. Warren & Co., 451 Greenwich St., New York City; residence, Roselle, N. J.	June 23, 1897
Atwood, George F.	Orange, N. J.	Sept. 16, 1890
Austin, Sydney B.	Metropolitan Electric Construction Co., 20 Broad Street; residence, 110 E. 18th Street, New York.	Sept. 25, 1895
Auerbacher, Louis J.	Auerbacher & Venino, Electrical Engineers and Contractors, 317 Market St., Newark, N. J.	Sept. 20, 1893
Babcock, Clifford D.	[Address unknown.]	Feb. 21, 1894
Badeau, Isaac F.	Assistant to the Engineer, New York Telephone Co.; residence, 244 Clinton St., Brooklyn, N. Y.	Feb. 26, 1896
Baldwin, Alfred De V.	Selling Agent, Crocker-Wheeler Electric Co , P. O. Box, 267; residence, 708 W. 85 St., New York.	Aug. 13, 1897
Balcome, Herbert A.	With The B. F. Sturtevant Co., Jamaica Plain Station, Mass.	Oct. 27, 1897
Baldwin, Jas. C. T.	Superintendent Bell Telephone Co., of Mo.; 10th and Olive Sts., St. Louis, Mo.	April 17, 1895
Ball, Wm. D.	Consulting Electrical Engineer, W. D. Ball & Co , 1625 Monadnock Block, Chicago, Ill.	Nov. 20, 1895
Balsley, Abe	Chief Electrician, Terre Haute Electric Railway Co., 514 No. 6½ Street, Terre Haute, Ind.	Oct. 27, 1897
Bancroft, Chas. F.	Electrical Engineer, Lowell and Suburban Street Railway, Lowell, Mass.	Dec. 18, 1895
Bangs, Chas. R.	Special Agent, American Telephone and Telegraph Co., 15 Dey St., New York.	Jan. 26, 1898
Banks, William C.	Electrician, Gordon-Burnham Battery Co., 82 West Broadway, New York City.	May 18, 1897
Barbour, Fred Fiske	Manager, Power and Mining Department, Pacific District, General Electric Co., 15 First St., San Francisco, Cal., and 1673 Valdez St., Oakland, Cal.	May 16, 1893
Barnes, Chas. R.	City Electrician and Electrical Expert to State R. R. Commission, Rochester, N. Y.	Aug. 13, 1897
Barnes, Edward A.	Electrical Expert, Fort Wayne Electric Co., Fort Wayne, Ind.	Sept. 20, 1893
Barry, David	Electrician and Superintendent, Amherst Gas Co., Amherst, Mass.	Aug. 5, 1896
Barstow, William S.	General Supt., Edison Electric Illuminating Co., 360 Pearl St., Brooklyn, N. Y.	Feb. 21, 1894
Barton, Enos M.	President Western Electric Co., 227 South Clinton St., Chicago, Ill.	July 12, 1887
Bates, Frederick C.	Electrical Engineer, General Electric Co., 44 Broad St., New York City.	Jan. 20, 1891

Name.	Address.	Date of Election.
Bates, Putnam A.	Student, Columbia University; residence, 113 West 72d St., New York City.	Jan. 20, 1897
Beames, Clare F.	Ingeniero, Mexican General Electric Co., Apartado 403, City of Mexico.	May 21, 1895
Beattie, John, Jr.	Manager and Superintendent, The Beattie Battery, Zinc and Electric Co., Fall River, Mass.	Sept. 6, 1887
Bechtel, Ernest J.	Superintendent, Power Plant, Toledo Traction Co., Toledo, O.	Mar. 24, 1897
Beebe, M. C.	Ass't. in Electrical Engineering, University of Wisconsin; residence, 271 Langdon St., Madison, Wis.	Jan. 26, 1898
Bell, Ora A.	Electrical Engineer, Western Electric Co., 22 Thames St., New York; residence, 921 St. Nicholas Ave., New York.	Aug. 5, 1896
Bennett, Edwin H., Jr.	Electrician and Engineer, Diehl & Co., Elizabethport, N. J., and 19 West 33d St., Bayonne, N. J.	June 20, 1894
Bennett, John C.	Electrician, General Electric Co., 44 Broad St., New York City.	Mar. 18, 1890
Benoliel, Sol. D., *B. S.*, *E. E.*, *A. M.*	Consulting and Contracting Electrical Engineer, 103 East 62nd Street, New York City	Oct. 21, 1896
Bentley, Merton H.	Chicago Telephone Co.; residence, 221 Scoville Ave., Oak Park, Ill.	Oct. 18, 1893
Berg, Ernst Julius	Engineer, General Electric Co.; residence, 53 Washington Ave., Schenectady, N. Y.	Sept. 19, 1894
Berg, Eskil	Electrical Engineer, Gen'l Electric Co., Schenectady, N. Y.	Nov. 20, 1895
Bergholtz, Herman	Secretary and Treasurer, Ithaca Street Railway Co., Ithaca, N. Y.	April 2, 1889
Berliner, Emile	Inventor, Columbia Road, between Fourteenth and Fifteenth Sts., Washington, D. C.	April 15, 1884
Berresford, Arthur W., *B. S.*, *M. E.*	Electrician, Ward Leonard Electric Co, Bronxville, N. Y.	May 15, 1894
Best, A. T.	Electrical Engineer, Florida East Coast Hotel System, St. Augustine, Fla.	April 19, 1894
Bethell, U. N.	General Manager, The New York Telephone Co., 18 Cortlandt St., New York City.	Jan. 17, 1894
Betts, Hobart D.	Member of Inspection Dept., The Edison Elec. Ill'm'g Co. of N. Y.; residence, Englewood, N. J.	Aug. 5, 1896
Betts, Philander 3d	Electrician, U. S. Navy Yard, Washington, D. C.	Mar. 25, 1896
Biddle, James G.	Drexel Bldg., Philadelphia, Pa.; residence, 264 Rittenhouse St., Germantown, Pa.	Aug. 5, 1896
Bijur, Joseph, *A. B.*, *E. E.* [Life Member.]	Walker Company, 1 Nassau St.; residence, 172 West 75th St., New York City.	May 15, 1894

Name.	Address.	Date of Election.
Black, Chas N.	Walker Company, 140 Winchester Ave., New Haven, Ct.	April 19, 1890
Black, Howard D.	Salesman, Blackall & Baldwin, 7 West 19th St.; P. O. Box, 267, New York, N. Y	Sept. 15, 1897
Blackall, Frederick, S.	Selling Agent, Crocker-Wheeler Electric Co , P. O. Box, 267 New York ; residence, Roselle, N. J.	Sept. 15, 1897
Blake, Henry W.	Editor, *Street Railway Journal*, 26 Cortlandt St., New York City.	Nov. 13, 1888
Blake, Theodore W.	Box, 263, New Haven, Conn.	Sept. 20, 1893
Blanchard, Charles M.	Winterburn, Pa.	Sept. 19, 1894
Blaxter, Geo. H.	Vice-President and General Manager, Allegheny County Light Co., Westinghouse Building, Pittsburg, Pa.	Sept. 25, 1895
Bliss, George S.	24 Chase, W. Lynn, Mass.	June 20, 1894
Bliss, Wm. J. A.	Johns Hopkins University ; residence, 1017 W. Paul St., Baltimore, Md.	Jan. 20, 1891
Bliss, William L., *B. S.*, *M. M. E.*	Electrical Engineer, 128 Front St., New York City; residence, 505 Throop Ave., Brooklyn, N. Y.	Mar. 21, 1894
Blizard, Charles	Manager of New York Office, Electric Storage Battery Co., 22 Broad St.; residence, 34 W. 27th St., New York City.	Nov. 21, 1894
Blunt, Willam W.	Electrical Engineer, Westinghouse Elec. & Mfg. Co , Ltd., 32 Victoria St., London, Eng.	Dec. 16, 1896
Bogart, A. Livingston	Electrical and Patent Expert, 22 Union Square, New York City.	July 10, 1888
Boggs, Lemuel Stearns	Reed Hotel, Ogden, Utah.	Sept. 20, 1893
Bogue, Charles J.	Manufacturer and Dealer in Electrical Supplies, 206 Centre St., N.Y. City.	Dec. 3, 1889
Bohm, Ludwig K., *Ph.D.*,	Consulting Electrical and Chemical Expert, 117 Nassau St., N. Y. City.	Nov. 15, 1892
Bolan, Thomas V.	Supervising and Constructing Engineer, The General Electric Co., Schenectady, N. Y.; residence, 869 N. 41st St., Philadelphia, Pa.	Aug. 5, 1896
Boyles, Thomas D.	Electrical Engineer, General Electric Co.; residence, 58 Washington Ave., Schenectady, N. Y.	Mar. 20, 1895
Brackett, Byron B.	Instructor Electrical Engineering, Union College, Schenectady, N. Y.	Nov. 30, 1897
Brackett, Prof. Cyrus F.	Princeton, N. J.	April 15, 1889
Braddell, Alfred E.	Electrical Inspector, Underwriters' Association, Middle Department, 316 Walnut St., Philadelphia, Pa.	Sept. 1, 1890
Brady, Frank W., *M. E.*	Professor of Engineering and Physics, New Mexico College of Agriculture and Mechanic Arts, Mesilla Park, N. M.	June 20, 1894

Name.	Address.	Date of Election.
Brady, Paul T.	Manager, Central N. Y. Agency, Westinghouse Electric and Mfg. Co., Syracuse, N. Y.	July 12, 1887
Bragg, Charles A.	Manager Phila. Agency, Westinghouse Electric and Mfg. Co., 302 Girard Building, Philadelphia, Pa.	Sept. 20, 1893
Brayshaw, I.	Telegraph Inspector Great Southern Railway, City of Buenos Aires.	Aug. 5, 1896
Brixey, W. R.	Proprietor and Manufacturer, Day's Kerite Wire and Cables, 203 Broadway, New York City.	Sept. 20, 1893
Broich, Joseph	Superintendent and Electrician, with F. Pearce, New York City; residence, 448 8th Ave. Brooklyn, N. Y.	Jan. 17, 1894
Brophy, William	Electrician to the Wire Department, 12 Old Court House, Boston; residence, 17 Egleston St., Jamaica Plain, Mass.	Mar. 5, 1889
Brown, Albert W.	Mechanical and Electrical Engineer, 192 Broadway; residence, 27 W. 24th St , New York.	Feb. 17, 1897
Brown, Chas. L.	Gen'l Manager and Sec'y, Chicago Mutoscope Co., 1309 Monadnock Block, Chicago, Ill.	Nov. 20, 1895
Brown, Hugh Thomas	Electrical Engineer, Nashville, Tenn.	Jan. 26, 1898
Browne, Sidney Hand.	Consulting Electrical Engineer, 809 Equitable Bldg., Baltimore; residence, Ruxton, Md.	Apr. 28, 1897
Bubert, J. F.	Supervising and Contracting Electrical Engineer, 402 Exchange Bldg., (Telephone 1379) Boston, Mass.	June 7, 1892
Buck, Harold W.	14 East 45th St., New York City.	Jan. 16, 1895
Buckingham, Chas. L.	Patent Attorney, Western Union Telegraph Co., 195 Broadway, P. O. Box 856, New York City.	April 15, 1884
Bunce, Theodore D.	The Storage Battery Supply Co., 239 E. 27th St., New York City.	May 20, 1890
Burch, Edward P.	Electrical Engineer, Twin City Rapid Transit Co., 517 6th Ave., S. E., Minneapolis, Minn.	Jan. 28, 1898
Burgess, Chas. Fred'k.	Instructor in Electrical Engineering, University of Wisconsin, Madison, Wis.	Mar. 25, 1896
Burke, James	Consulting Electrical Engineer, 150 Nassau St., New York City.	May 16, 1893
Burnett, Douglass, *B.S.*	Edison Illuminating Co., Inspection Dept., 55 Duane St., New York City; residence, 42 Livingston St., Brooklyn, N. Y.	Feb. 21, 1893
Burroughs, Harris S.	1416 Pacific St., Brooklyn, N. Y.	Nov. 30, 1897
Burt, Byron T.	Manager and Sec'y, and Treas. Charleston Light and Power Co., Charleston, S. C.	Sept. 25, 1895
Burton, Paul G.	Constructing Electrician, Western Electric Co.; residence, 149 Lenox Ave, New York City.	Nov. 20, 1895
Burton, William C.	With White-Crosby Co., 29 Broadway, New York, N. Y.	Sept. 20, 1893

Name.	Address.	Date of Election.
BUTLER, WILLIAM C.	President, The Puget Sound Reduction Co., Everett, Washington.	Mar. 21, 1893
BUYS, ALBERT	Electrical Engineer, The Rahway Electric Light and Power Co., Rahway, N. J.	Feb. 7, 1890
BYRNS, ROBERT A.	Walker Company, 912 Ellicott Square, Buffalo, N. Y.	Dec. 16, 1896
CABOT, FRANCIS ELLIOTT	Supt. of Inspection and Electrician, Boston Board of Fire Underwriters, 55 Kilby Street; residence, East Milton, Mass.	April 17, 1895
CABOT, JOHN ALFRED	City Electrician, 115 W. 8th St., Cincinnati, O.	May 16, 1893
CALDWELL, EDWARD	President Empire Advertising Co., 150 Nassau St., New York City; residence, 407 E. 5th St., Plainfield, N. J.	Jan. 20, 1891
CALDWELL, FRANCIS C.	Assistant Professor of Electrical Engineering, Ohio State University, Columbus, O.	June 20, 1894
CANFIELD, MILTON C.	Electrical Engineer, The Cleveland City Railway Co.; residence, 18 Clinton St., Cleveland, O.	Feb. 21, 1893
CANFIELD, MYRON E.	Western Electric Co.; residence, 404 W. 44th St. New York City.	May 21, 1895
CAPUCCIO, MARIO	Raimondo & Capuccio, Consulting Engineers and Patent Agents, Piazza Statuto 15, Turin, Italy.	Dec. 20, 1893
CARICHOFF, E. R.	Electrical Engineer, Sprague Electric Co., Bloomfield, N. J.	Mar. 21, 1894
CARPENTER, CHAS. E.	Vice-President, Carpenter Enamel Rheostat Co.; residence, 36 W. 35th St., New York.	Aug. 5, 1896
CARSON, DAVID I.	Secy. and Gen. Supt., The Southern Bell Telephone and Telegraph Co., 26 Cortlandt St., New York City.	Dec. 21, 1892
CARTER, HENRY W.	Attorney and Expert in Patent Causes, Carter & Graves, 810 Reaper Block, Chicago, Ill.	Apr. 28, 1897
CARTY, J. J.	Engineer, New York Telephone Co., 15 Dey St., New York City; residence, Cranford, N. J.	April 15, 1890
CASE, WILLARD E.	196 Genesee St., Auburn, N. Y.	Feb. 7, 1888
CASPER, LOUIS	Electricial Engineer and Contractor, 3122 Wabash Ave., Chicago, Ill.	April 21, 1891
CHADBOURNE, HENRY R., JR.	Electrical Engineer, 130 Bedford St., Boston, Mass.	May 15, 1894
CHAPMAN, A. WRIGHT	Electrical Engineer, 160 Hicks St., Brooklyn, N. Y.	Mar. 25, 1896
CHENEY, FREDERICK A.	Maple Avenue, Elmira, N. Y.	Oct. 1, 1889
CHERMONT, ANTONIO LEITE	Engineer, Firm of Chermont, Silva and Miranda, Box 252, Para, U. S. Brazil.	Mar. 18, 1890

Name.	Address.	Date of Election.
CHESNEY, C. C.	Electrician, Stanley Laboratory, Pittsfield, Mass.	June 20, 1894
CHILDS, SUMNER W.	c/o J. G. White Co.. 706 Equitable Bldg., Baltimore, Md.	May 15, 1894
CHILDS, WALTER H.	Brattleboro, Vt.	Sept. 6, 1887
CHISM, GEORGE F.	Civil Engineer, 3 No. Pearl Street, Albany, N. Y.	Mar. 21, 1893
CHUBBUCK, H. EUGENE	Vice-President, The Pueblo Electric Street Railway Co., Pueblo, Col.	Dec. 4, 1888
CLARK, CHAS. M.	Student, Electrical Course, Columbia University ; residence, 831 Madison Ave., New York City.	April 22, 1896
CLARK, LEROY, JR.	Electrical Engineer of the Safety Insulated Wire and Cable Co., 229 West 28th St., residence, 208 West 85th St., New York City.	May 15, 1894
CLARK, WILLIAM J.	General Manager, Railway Dept. General Electric Co., 44 Broad Street, New York City.	April 22, 1896
CLEMENT, EDWARD E.	Ass't Examimer, Electrical Division, U. S, Patent Office, Washington, D C.	May 18, 1897
CLEMENT, LEWIS M.	1013 Central Ave., Oakland, Cal.	April 21, 1891
CLOUGH, ALBERT L.	Box 114, Manchester, N. H.	Feb. 21, 1894
CODY, L. P.	Manager and Engineer, Grand Rapids Electric Co., 9 South Division St., Grand Rapids, Mich.	Aug. 5, 1896
COFFIN, CHAS. A.	General Electric Co., 180 Summer St., Boston, Mass.	Dec. 6, 1887
COGSWELL, A. R.	Electrician and Superintendent, Halifax Illuminating and Motor Co., Ltd., 34 Bishop St., Halifax, N. S.	April 21, 1891
COHO, HERBERT B.	H. B. Coho & Co., Electrical Engineers, 220 Broadway, New York City.	Mar. 21, 1894
COLES, EDMUND P.	Resident Engineer, Manáos Electric Lighting Co., Manáos, U. S. Brazil.	Oct. 23, 1895
COLGATE, GEO. L.	Electrical Engineer, Ironclad Rheostat Co., Westfield, N. J.; residence, Fanwood, N. J.	June 17, 1890
COLLETT, SAMUEL D.	Eastern Manager, Elevator Supply and Repair Co., 136 Liberty St., New York City; residence, Van Pelt Manor, N. Y.	Feb. 26, 1896
COLVILLE, FRANK C.	Electrician and Inventor, 1503 Seventh Ave., Oakland, Cal.	May 19, 1891
COMPTON, ALFRED G.	Professor of Applied Mathematics, College of the City of New York, 17 Lexington Ave., New York City.	Nov. 1 1887
COOLIDGE, CHARLES A.	Electrical Engineer, Portland Ceneral Electric Co , 12 Selling-Hirsch Bldg. Portland, Ore.	April 19, 1892

Name.	Address.	Date of Election.
COPELAND, CLEMENT A.	Assistant Superintendent, Edison Electric Co., Los Angeles, Cal.	June 23, 1897
COREY, FRED BRAINARD	Sec'y Springfield Elevator and Pump Co., Springfield, Mass.	Dec. 20, 1893
CORNELL, JOHN B.	Supt. of Construction, with Chas. L. Cornell, Hamilton, O.	Sept. 25, 1895
CORSON, WILLIAM R. C.	Electrical Engineer, The Eddy Electric Mfg. Co., Windsor, Conn.	Jan. 17, 1893
CORY, CLARENCE L.	Professor of Electrical Engineering, University of California, Berkeley, Cal.	April 19, 1892
CRAIN, JOHN JAY,	American Impulse Wheel Co., 120 Liberty St., New York City.	Dec. 16, 1896
CRANDALL, CHESTER D.	Assistant Treasurer, Western Electric Co., 227 South Clinton St.; residence, 4438 Ellis Ave. Chicago, Ill.	Sept. 27, 1892
CRANE, W. F. D.	Manager Electrical Department H. W. Johns Manufacturing Co., 100 William Street, New York City; residence, 24 Halstead Pl., East Orange, N. J.	Feb. 7, 1888
CRAWFORD. DAVID FRANCIS	Ass't to Supt. Motive Power, Penn'a Co., Fort Wayne, Ind.	Sept. 25, 1895
CRAWFORD, L. G.	Sup't, Repair Dep't General Electric Co., Chicago, Ill,	Oct. 23, 1895
CREAGHEAD, THOMAS J.	President and General Manager, Creaghead Engineering Co., 296 Plum St., Cincinnati, O.	Sept. 20, 1893
CREHORE, ALBERT C., *Ph.D.*	Assistant Professor of Physics, Dartmouth College, Hanover, N. H.	Dec. 21, 1892
CREWS, J. W.	Manager, Southern Bell Telephone and Telegraph Co., 124 Main St., Norfolk, Va.	Sept. 19, 1894
CRIGGAL, JOHN E.	Electrician, 61 Stirling Street, Newark, N. J.	June 20, 1894
CROCKER, EBEN CLINCH	Electrical Engineer, American Ordnance Co., 29 Harriet Street, Bridgeport, Conn.	Jan. 26, 1898
CROSBY, OSCAR T.	White-Crosby Co., 1417 G Street, Washington, D. C.	Mar. 18, 1890
CUMNER, ARTHUR B.	64 Federal St., Boston, Mass.	Feb. 27, 1895
CUNNINGHAM, E. R.	Sup't Fort Dodge Light and Power Co., Fort Dodge, Iowa.	Jan. 22, 1896
CUNTZ, JOHANNES H.	Assistant to President Henry Morton, Stevens Institute of Technology, 325 Hudson St., Hoboken, N. J.	Mar. 5, 1889
DACUNHA, MANOEL IGNACIO	Manager of the Electrical Section, Emprera Industrial Gram-Para, Para, U. S. of Brazil.	May 16, 1893
DAME, FRANK L.	General Sup't, Tacoma Railway and Motor Co., Tacoma, Wash.	June 26, 1891

Name.	Address.	Date of Election.
DAMON, GEO. B.	Metropolitan Electric Construction Co., 20 Broad St., New York City.	June 23, 1897
DANA, R. K.	Agent, Washburn and Moen Mfg. Co., 16 Cliff St., New York City.	April 15, 1884
DANIELSON, ERNST	Consulting Electrician, 16 Scheele Gatan, Stockholm, Sweden.	June 27, 1895
DARROW, ELEAZAR	Professor M. E. Dept. Washington Agr. College, Pullman, Wash.	Aug. 5, 1896
DAVENPORT, C. G.	Expert and Agent, General Electric Co., 44 Broad St., New York City.	Nov. 21, 1894
DAVENPORT, GEORGE W.	61 Ames Bldg., Boston, Mass.	June 4, 1889
DAVIDSON, EDW. C.	Patent Lawyer, Room 179 Times Bldg., New York City.	Feb 7, 1890
DAVIS, DELAMORE L.	Superintendent, Salem Electric Light and Power Co., 299 Lincoln Ave., Salem, O.	April 2, 1889
DAVIS, JOSEPH P.	Engineer, American Bell Telephone Co., 113 W. 38th St., New York City.	April 15, 1884
DAVIS, W. J., JR.	Electrical Engineer, General Electric Co., Schenectady, N. Y.	Mar. 20, 1895
DEGEN, LEWIS	Constructing Engineer, Gen'l Electric Co., Rio de Janeiro, Brazil.	Sept. 25, 1895
DEKHOTINSKY, CAPT. ACHILLES,	Late Chief Electrician and Torpedo Officer, Imperial Russian Navy, Western Electric Co., Chicago, Ill.	Oct. 27, 1891
DELANCEY, DARRAGH	Manager of Kodak Park Works, Eastman Kodak Co., Rochester, N. Y.	Sept. 19, 1894
DENTON, JAMES E.	Professor of Experimental Mechanics, Stevens Institute of Technology, Hoboken, N. J.	July 12, 1887
DEREDON, CONSTANT	Consulting Engineer, 27 Thames St., New York City.	May 18, 1897
DEWAR, JOHN THOMAS	Electrical Expert, Western Electric Co.; residence, 33 Rue Bouewijns, Antwerp, Belgium.	May 21, 1895
DEY, HARRY E.	Pres't and Gen'l Mgr. Dey-Griswold Co., residence, 62 Church St., Pawtucket, R. I.	Dec. 19, 1894
DICKERSON, E. N.	Attorney-at-Law, 64 E. 34th St., New York City.	April 15, 1884
DINKEY, ALVA C.	Supt. Electric Dept., Homestead Steel Works, Munhall, Pa.	Feb. 17, 1897
DOBBIE, ROBERT S.	Electrical Engineer, Riding Mill-on-Tyne, Northumberland, Eng.	Feb. 5, 1889
DOOLITTLE, CLARENCE E.	Manager and Electrician, Roaring Fork Electric Light and Power Co., Aspen, Colo.	May 15, 1894
DOOLITTLE, THOMAS B.	Engineering Department, American Bell Telephone Co., 125 Milk St., Boston, Mass.	May 16, 1893

Name.	Address.	Date of Election.
DOREMUS, CHARLES AVERY	*M.D. Ph.D.* 59 W. 51st St., New York City.	July 7, 1884
DRESSLER, CHARLES E.	17 Lexington Ave., New York City.	Dec 16, 1890
DRYSDALE, WILLIAM A.	Consulting Electrical Engineer, Hale Building, Philadelphia, Pa.	Sept. 19, 1894
DU BOIS, JULIAN	Chief Electrician, Mohawk Division N. Y. C. & H. R. R. R. Albany, N. Y.	Nov. 20, 1895
DUNCAN, JOHN D. E.	76 Miller Ave., Ann Arbor, Mich.	Mar. 20, 1895
DUNCAN, THOMAS	Electrician, Laboratory Fort Wayne Electric Corporation, 407 Broadway, Fort Wayne, Ind.	Oct. 17, 1894
DUNLAP, WILL KNOX	Electrical Engineer, Westinghouse Elec. and Mfg. Co., Niagara Falls, N. Y.	Sept. 25, 1895
DUNN, KINGSLEY G.	Dunn & McKinley, Electrical Contractors, 523 Mission St., San Francisco, Cal.	Oct. 17, 1894
DURANT, EDWARD	Chief Electrical Engineer, Manhattan State Hospital of the State of New York, Ward's Island, N. Y.; residence, 115 East 26th St., New York City.	Nov. 15, 1892
DURANT, GEO. F.	Vice-Pres't Bell Telephone Co., of Mo., 511 No. 4th St., St. Louis, Mo.	April 15, 1884
DYER, FRANCIS MARON	Associate Engineer with Chas. L. Eidlitz, 10 West 23d St ; residence, 355 Lenox Ave., New York City.	Sept. 19, 1894
EDDY, H. C.	Electrical Engineer and Contractor, Lees Building, Chicago, Ill.	June 20, 1894
EDEN, MORTON EDWARD	Electrical Inspector, Western District the Underwriters' Association of the Middle Department, 245 Fourth Ave., Pittsburg ; residence, Warren Pa.	Sept. 19, 1894
EDMANDS, I. R.	Construction Engineer, General Electric Co., 706, The Phoenix, Minneapolis, Minn.	June 23, 1897
EDWARDS, JAMES P.	Electrical Engineer, 1569 Walton Way, Augusta, Ga.	April 19, 1892
EGLIN, WM. C. L.	Chief of Electrical Department, Edison Electric Light Co., 909 Walnut St.; residence, 4230 Chester Ave., Philadelphia, Pa.	Sept. 19, 1894
EKSTROM, AXEL	Electrical Engineer, General Electric Co.; Schenectady, N. Y.	June 17, 1890
ELEY, HARRIS H.	Electrical Workshop Supt. W. C. & S. W. Telephone Co., 88 Colston St., Bristol, Eng.	Jan. 7, 1890
ELLARD, JOHN W.	Treasurer, Edison Electric Illuminating Co., 15 South Street, Baltimore, Md.	June 23, 1897
ELIAS, ALBERT B.	Electrician, Davis Coal and Coke Co., Thomas, West Va.	Jan. 26, 1898

Name.	Address.	Date of Election.
ELLICOTT, EDWARD B.	Superintendent of City Telegraph, Union League Club, Chicago, Ill.	Sept. 19, 1894
ELMER, WILLIAM, JR.	Electrical Engineer, 68 Park Place, Newark, N. J.	Mar. 18, 1890
ELY, WM. GROSVENOR, JR.	8 Union Street, Schenectady, N. Y.	Mar. 21, 1893
EMERICK, LOUIS W.	Electrical Engineer, The Solvay Process Co., Syracuse, N. Y ; residence 208 East Jefferson St., Syracuse, N. Y.	Aug. 13, 1897
EMMET, HERMAN L. R.	Publisher and Printer, 36 Cortlandt St., New York City.	April 15, 1884
ENDE, SIEGFRIED H.	121 E. 77th St., W. New York City.	Jan. 17, 1894
ENTZ, JUSTUS BULKLEY	Electrical Engineer, Electric Storage Battery Co., 19th St., and Allegheny Ave., Philadelphia, Pa.	Jan. 7, 1890
ERICKSON, F. WM.	Electrical Engineer, Lord Electric Co., 181 Tremont St., Boston, Mass.	Sep. 19, 1894
ESTY, WILLIAM	Assistant Professor of Electrical Engineering, State University, Urbana, Ill.	Mar. 20, 1895
ETHERIDGE, LOCKE	Chicago Telephone Co.; residence, 44 E. 50th St., Chicago, Ill.	Oct. 17, 1894
ETHERIDGE, E. L.	Care of J. P. Hall, 143 Liberty St., New York City.	Dec. 20, 1893
EVANS, EDWARD A.	Acting Chief Engineer, The Quebec, Montmorency and Charlevoin Railway, Quebec, Canada.	Jan. 22, 1896
EYRE, M. K.	Manager Harrison Works, General Electric Co., Harrison, N. J.	Oct. 17, 1894
FARNSWORTH, ARTHUR J.	Chief Engineer, Larchmont Electric Co., Mamaroneck, Conn.	Jan. 16, 1895
FAY, THOMAS J.	Crocker-Wheeler Electric Co., 39 Cortlandt St., New York City.	June 26, 1891
FIELDING, FRANK E. [Life Member.]	Chemist and Assayer, Virginia City, Nev.	Sept. 6, 1887
FIRTH, WM. EDGAR	Chief Engineer, The Midvale Steel Co., Nicetown, Philadelphia ; residence, 7203 Boyer St., Germantown, Pa.	Mar. 25, 1896
FISCHER, GUSTAVE J.	Engineer for Tramway Construction, Public Works Department, Sydney, N. S. W.	Jan. 20, 1891
FISH, MILTON L.	306 Bryant St., Buffalo, N. Y.	Oct. 21, 1896
FISHER, HENRY W.	Electrician and Director of Elec. and Chem. Laboratories; The Standard Underground Cable Co., Pittsburg, Pa.	Jan. 16, 1895
FISKE, J. PARKER B.	164 Devonshire St., Boston, Mass.	June 17, 1890
FLATHER, JOHN J.	Professor of Mechanical Engineering, Purdue University, Lafayette, Ind.	April 19, 1892

Name.	Address.	Date of Election.
FLESCH, CHARLES	Electrical Engineer, Allgemeine Elektricitats-Gesellschaft, 22 Schiffbauerdamm, Berlin, N. W. Germany.	Sept. 27, 1892
FLOOD, J. F.	Sup't Steubenville Traction Co., Steubenville, O.	Mar. 18, 1890
FLORY, CURTIS B.	Link Belt Engineering Co., Nicetown, Philadelphia, Pa.	April 22, 1896
FLOY, HENRY	Engineer Westinghouse Electric and Mfg. Co., 171 La Salle St.; residence, 5540 Cornell Ave., Chicago, Ill.	May 17, 1892
FOOTE, CHARLES W.	General Manager, Citizens Traction Co., San Diego, Cal.	Sept. 22, 1891
FOOTE, THOS. H.	Electrical Engineer, C. & C. Electric Co., Garwood, near Westfield, N. J.	April 21, 1891
FORBES, FRANCIS	Lawyer, 32 Nassau St., New York City.	Sept. 16, 1890
FORBES, GEORGE	Electrical Engineer, 34 Great George St., London, Eng.	Feb. 21, 1894
FORD, ARTHUR HILLYER,	706 University Ave., Madison, Wis.	Mar. 24, 1897
FORD, FRANK R., *M. E.*	Consulting Engineer, Ford, Bacon & Davis, 220 Broadway, New York City.	Mar. 25, 1896
FORD, WM. S.	Assistant to Chief Engineer, The American Bell Telephone Co., room 73, 125 Milk St., Boston, Mass.	June 7, 1892
FRANCISCO, M. J.	President and General Manager, Rutland Electric Light Co., Rutland, Vt.	June 17, 1890
FRANKENFIELD, BUDD	Instructor in Electrical Engineering, State College, Center Co., Pa.	Feb. 17, 1897
FRANKLIN, W. S.	Lehigh University, South Bethlehem, Pa.	Jan. 22, 1896
FRANTZEN, ARTHUR	Electrical Engineer and Contractor, 225 Dearborn St., Chicago, Ill.	Feb. 21, 1894
FRENCH, PROF. THOMAS, JR. *Ph.D.*	Avondale, Cincinnati, O.	Sept. 20, 1893
FRENYEAR, THOMAS C.	Westinghouse Electric and Mfg. Co., Guaranty Bldg., Buffalo, N. Y.	Sept. 25, 1895
FRIDENBERG, HENRY LESLIE, *M. E.*	Stanley Mfg. Co., (Meter Dept.,) Pittsfield, Mass.	Jan. 16, 1895
FRIEDLAENDER, EUGENE	Electrician, Carnegie Steel Company, Duquesne, Pa.	Nov. 20, 1895
FROST, JOSEPH W.	Secretary, National Automatic Fire Alarm, 335 Broadway, New York City.	Mar. 20, 1895
GALLAHER, EDWARD B.	Consulting and Supervising Engineer, 120 Liberty Street; residence, 1190 Madison Ave., New York City.	Jan. 19, 1895
GARRELS, W. L.	4531 West Pine Boulevard, St. Louis, Mo.	Mar. 20, 1895
GARFIELD, ALEX. STANLEY	Engineer, Cie Thomson-Houston, 27 Rue de Londres, Paris, France.	Jan. 26, 1898
GERRY, JAMES H.	Superintendent, The Self-Winding Clock Co., 163 Grand Ave., Brooklyn, N. Y.	April 18, 1894
GERSON, LOUIS JAY	Engineer and Contractor, 712 Sansom St.; residence, 637 S. 49th St., Philadelphia, Pa.	Sept. 19, 1894

Name.	Address.	Date of Election.
Gherardi, Bancroft, Jr.,	Assistant in the Engineering Dept. New York Telephone Co.; residence, 30 East 33d St., N. Y. City.	June 27, 1895
Gilliland, E. T.	Pelham Manor, N. Y.	April 15, 1884
Gilmore, Lucien H.	Prof. of Physics and Electrical Engineering, Throop Polytechnic Institute, Pasadena, Cal.	Mar. 20, 1895
Githens, Walter L.	Manager, H. P. Elec. Light and Power Co., 7284 So. Chicago Ave.; residence, 5101 Kimbark Ave., Chicago, Ills.	Jan. 22, 1896
Glading, Frank W., *M. E.*, *M. S.*	Edison Manufacturing Co., West Orange, N. J.	May 15, 1894
Gladstone, James Wm.	Manager, Edison Mfg. Co., 110 East 23d St., New York City; residence, West Orange, N. J.	April 18, 1894
Goddard, Chris. M.	Secretary and Electrician, New England Insurance Exchange. Sec'y Underwriters' National Electric Ass'n, 55 Kilby St,, Boston, Mass.	April 22, 1896
Goldmark, Chas. J.	Electrical Engineer, 39 Cortlandt St., and 473 Park Ave., New York City.	June 5, 1888
Goldsborough, Winder Elwell, *M. E.*,	Professor of Electrical Engineering, Purdue University, Lafayette, Ind.	Mar. 21, 1893
Gorton, Charles	Civil Engineer, Belmont, N. Y.	Nov. 12, 1889
Gordon, Reginald	Tutor in Physics, Columbia University, New York City.	Feb. 24, 1891
Gorrissen, Ch.	With Siemens & Halske, Franklinstrasse 29, Charlottenburg, Ger.	Mar. 25, 1896
Gossler, Philip Green	Electrical Engineer, Royal Electric Co. 94 Queen St., Montreal, P. Q.	June 20, 1894
Gott, Clarence P.	83 Washington Place, New York City.	Nov. 20, 1895
Graham, George Wallace	80 Decatur St., Brooklyn, N. Y.	Dec. 19, 1894
Granbery, Julian H.	Draughtsman, residence, Closter, N. J.	Aug. 5, 1896
Graves, Chas. B.	Marblehead, Mass.	Sept. 15, 1897
Greenleaf, Lewis Stone	Electrician, Hudson River Telephone Co., Albany, N. Y.	Aug. 5, 1896
Green, Elwyn Clinton	Testing Department and Installing Work, Jenney Electric Motor Co., 206 South East St., Indianapolis, Ind.	Mar. 25, 1896
Greenwood, Fred. A.	Secretary California Electric Works, 409 Market St., San Francisco, Cal.	April 28, 1897
Griffen, John D.	Inventor, Electric Conduit and Electric Signaling Apparatus, 60 Broadway; residence, 304 West 90th St., New York.	Aug. 13. 1897
Griffes, Eugene	Electrical Engineer, 534 South Broadway, Los Angeles, Cal.	Feb. 26, 1896

Name.	Address.	Date of Election
Griffin, Capt. Eugene	First Vice-President, General Electric Co., 44 Broad St., New York City.	Feb. 7, 1890
Gross, S. Ross	Electrician, Tennessee Coal, Iron and R.R. Co., Ensley, Ala.	May 17, 1892
Grower, George G.	Electrician and Chemist, Ansonia Brass and Copper Co., Ansonia, Conn.	Mar. 18, 1890
Guy, George Heli	Secretary, The New York Electrical Society, 120 Liberty St , New York City.	May 16, 1893
Hadley, Arthur L.	Assistant Electrician to Chief Electrician and Gen'l Supt., Fort Wayne Electric Corporation, 174 W. Craighton Ave., Fort Wayne, Ind.	Oct. 17, 1894
Hadley, Fred'k W.	Electrical Eng'r, Arlington Heights, Mass.	Aug. 5, 1896
Hakonson, Carl Harold	Electrical Engineer, with the Union Elektricitäts Gesellschaft, Hollmann Str. 32, Berlin S. W., Ger.	Sept. 25, 1895
Hall, Edward J.	Vice-President and General Manager, American Telephone and Telegraph Co., 15 Dey St., New York City.	April 18, 1893
Hall, J. P.	Electrical Contractor, 143 Liberty St.; residence, 200 W. 136th St., N. Y.	Aug. 5, 1896
Hall, William P.	President, The Hall Signal Co., Vice-President The Johnson Railroad Signal Co., 44 Broad St., New York City.	Sept. 16, 1890
Halsey, William B.	Electrician and Horologist, 246 Elton St., Brooklyn, N. Y.	Mar. 18, 1890
Hamerschlag, Arthur A.	Electrical Expert, and Owner Hamerschlag & Co., 100 Maiden Lane, New York City.	Mar. 25, 1896
Hammatt, Clarence S.	Supt., Jacksonville Electric Light Co., Jacksonville, Fla.	Sept. 20, 1893
Hanchett, Geo. T.	Electrical and Technical Engineer, 123 Liberty St., N. Y.; residence, Hackensack, N. J.	May 19, 1896
Hancock, L. M.	P. O. Box 151. Nevada City, Cal.	May 19, 1891
Harding, H. McL.	1 Nassau Street, New York City.	May 24, 1887
Harris, George H.	Electrical Engineer, Birmingham Railway and Electric Co., Birmingham, Ala.	June 20, 1894
Harris, W. C., Jr.	Electrician, Harris & Williamson, Birmingham, Ala.	April 17, 1895
Hartman, Herbert T.	Cor. 10th and Sansom Streets, Philadelphia, Pa.	Mar. 21, 1893
Harvey, Robert R. [Life Member.]	10 So. Franklin St., Wilkes-Barre, Pa.	Sept. 25, 1895

Name.	Address.	Date of Election.
HATHAWAY, JOSEPH D., JR.	Assistant in Cable Dep't Western Electric Co., 57 Bethune St., N. Y. City.	Aug. 5, 1896
HATZEL, J. C.	Electrical Engineer and Contractor, 114 Fifth Ave., New York City.	Sept. 3, 1889
HEALY, LOUIS W.	Mechanical Engineer's Office, Altoona, Pa.	June 26, 1891
HEDENBERG, WM. L.	Firm of Hedenberg & Kinsey, Consulting and Constructing Engineers, 108 Fulton St.; residence, 83 Clinton Place, New York City.	Nov. 21, 1894
HELLICK, CHAUNCEY GRAHAM	Electrical Engineer, The Chicago Telephone Co.; residence, 193 Dearborn Ave., Chicago, Ill.	Jan. 26, 1898
HENDERSON, ALEX.	Chief Inspector, New York Fire Dept.; residence, 321 West 118th St. N. Y.	Nov. 30, 1897
HENDERSON, HENRY BANKS	Riverside, Cal.	May 21, 1895
HERMESSEN, JOHN LOUIS	Chief of Data Dept., Union Elektricitäts Gesellschaft, Kleist Strasse 29, Berlin, Germany.	Jan. 20, 1897
HESSENBRUCH, GEORGE S. *E.E. Ph.D.*	Berliner Str. 75, Charlottenburg, Germany.	June 27, 1895
HEWITT, CHARLES E.	Electrician, Hyer-Sheehan Electric Motor Co., 100 Johnson St., Newburgh, N. Y.	Sept. 25, 1895
HEWITT, WILLIAM R.	Superintendent, Fire Alarm and Police Telegraph, 9 Brenham Place, San Francisco, Cal.	May 15, 1894
HEWLETT, EDWARD M.	Electrical Engineer, Railway Dept. General Electric Co., Schenectady, N. Y.	May 19, 1891
HILL, GEORGE, *C.E.*	Consulting Engineer, 41 Broadway, New York City.	April 19, 1892
HILL, H. P.	Washington Loan and Trust Building, Washington, D. C.	Nov. 18, 1897
HILL, NICHOLAS S., JR.	Chief Engineer Water Department, City Hall, Baltimore, Md.	Aug. 5, 1896
HOAG, GEO. M.	City Electrician, City of Cleveland, 115 City Hall; residence, 3 Dorchester Ave., Cleveland, O.	April 28, 1897
HOBART, HENRY M.	Engineer, care British Thomson-Houston Co., 83 Cannon St., London Eng.	April 18, 1894
HOCHHAUSEN, WILLIAM	Electrician, 40 4th Ave., Brooklyn, N. Y.	April 15, 1884
HOLBERTON, GEORGE C.	Electrical and Mechanical Engineer, Bangkok, Siam,	May 15, 1894
HOLBROW, HERMAN L.	With New York Telephone Co., New York City; residence, Rutherford, N. J.	Mar. 24, 1897
HOLT, MARMADUKE BURRELL,	Mining and Electrical Engineer, 287 Lexington Ave. New York, N.Y.	April 15, 1890
HOMMEL, LUDWIG	Supt. of Construction, Standard Underground Cable Co., Westinghouse Building, Pittsburg, Pa.	Jan. 20, 1897

Name.	Address.	Date of Election.
Hood, Ralph O.	Electrical Engineer, Danvers, Mass.	April 18, 1894
Hopewell, Chas. F.	Inspector of Wires, Supt. of Lamps, Fire Alarm and Police Telegraph, City of Cambridge, City Hall; residence, 82 Magazine St., Cambridgeport. Mass.	Aug. 13, 1897
Hopkins, Nevil Monroe	Electrical Engineer, 1730 I Street, Washington, D. C.	Nov. 20, 1895
Hornsby, Harry H.	Electrical Inspector, 16 City Hall, Chicago, Ill.	June 27, 1895
Hosmer, Sidney	Sup't. Underground Cable Dep't, Boston Electric Light Co, Ames Building, Boston, Mass.	May 18, 1897
Howson, Hubert	Patent Lawyer, 38 Park Row, New York City.	June 8, 1887
Hubbard, Albert S.	Electrical and Mechanical Engineer, The Electro Chemical Storage Battery Co., Belleville, N. J.	Nov. 20, 1895
Hubbard, William C.	Vice-President, The Electric Arc Light Co., 150 Nassau St., New York City; residence, 427 West 7th St., Plainfield, N. J.	April 18, 1894
Hubley, G. Wilbur	Electrical Engineer, Louisville Electric Light Co.; residence, 717 Fourth Ave, Louisville, Ky.	Sept. 19, 1894
Hubrecht, Dr. H. F. R.	Director, Nederlandsche Bell Telephone Co., Amsterdam, Holland.	Oct. 4, 1887
Hudson, John E.	President, The American Bell Telephone Co., 125 Milk St., Boston, Mass.	Dec. 20, 1893
Huggins, N. W.	Salesman, etc., General Electric Co., Seattle, Wash.	Aug. 5, 1896
Huguet, Chas. K.	Electrical Engineer, 1216 Carondelet St., New Orleans, La.	June 27, 1895
Hull, S. P.	Chief Electrician of Hudson Div. N. Y. C. & H. R. R. R. Co., Poughkeepsie, N. Y.	May 19, 1896
Hulse. Wm. S.	Electrical Engineer, Fort Wayne Electrical Corporation, 228 Fairfield Ave., Fort Wayne, Ind.	Mar. 25, 1896
Humphreys, C. J. R.	Manager, Lawrence Gas Co., and Edison Electrical Ill. Co., Lawrence, Mass.	Sept. 6, 1887
Hunt, Arthur L.	Electrician, W. R. Fleming & Co., 203 Broadway, New York City.	Sept. 19, 1894
Huntley, Chas. R.	General Manager, Buffalo General Electric Co., 40 Court St., Buffalo, N. Y.	Sept. 25, 1895
Hutchinson, Frederick L.	Electrical Engineer, Westinghouse Electric and Mfg. Co., Pittsburg, Pa.	June 20, 1894
Idell, Frank E.	Havemeyer Building, 26 Cortlandt St., New York City.	July 12 1887

Name.	Address.	Date of Election.
IHLDER, JOHN D.	Electrical Engineer, Otis Electric Co., Yonkers, N. Y.	Oct. 2, 1888
IIJIMA ZENTARO,	In charge of Transformer Testing Dep't., Wagner Elec. Mfg. Co., 2017 Locust St., St. Louis, Mo.	Jan. 22, 1896
INGOLD, EUGENE	Consulting Engineer and Expert, 1669 Second Ave., Pittsburg, Pa.	April 18, 1894
INSULL, SAMUEL	President, Chicago Edison Co., 139 Adams St., Chicago, Ill.	Dec. 7, 1886
IRVINE, DREW W.	[Address unknown.]	Sept 25, 1895
IWADARE, KUNIHIKO	Electrician, 19 Second St., Nakanoshima, Japan.	Sept. 20, 1893
JACKSON, WM. B.	New York and Staten Island Electric Co., West New Brighton, N. Y.	Aug. 13, 1897
JACKSON, WM. STEELL	So. Bell Telephone and Telegraph Co., Jacksonville, Fla.	April 22, 1896
JAEGER, CHARLES L.	Inventor, Maywood, N. J.	Dec. 20, 1893
JOHNSTON, W. J.	*The Electrical World*, 253 Broadway. New York City.	April 15, 1884
JONES, ARTHUR W.	Care of Gibbs, Bright & Co., Melbourne, Australia.	Oct. 17, 1894
JONES, F. R.	Professor of Machine Design, University of Wisconsin, Madison, Wis.	May 20, 1890
JONES, G. H.	Agent, General Electric Co., Casilla 1317 D Santiago, Chile.	April 17, 1895
JONES, HENRY C.	Member of Firm, the Electric Construction and Supply Co.,. Montgomery, Ala.	Mar. 20, 1895
JONES, M. E.	Contractor, and Student in Senior Class, Cornell University, Ithaca, N. Y.	Oct. 27, 1897
JUDSON, WM. PIERSON	U. S. Civil Engineer, Oswego, N. Y.; temporary address, 896 Ellicott Square, Buffalo, N. Y.	June 8, 1887
KAMMERER, JACOB A.	General Agent, The Royal Electric Co., Toronto; residence, 97 Macdonell Ave., Toronto, Ont.	April 28, 1897
KAMMEYER, CARL E.	Electrical Engineer, Maywood Ill.	Sept. 19, 1894
KEEFER, EDWIN S.	Supt. of Electric Light Construction, Western Electric Co ,57 Bethune St., New York City; residence, Elizabeth, N. J.	April 18, 1894
KEILHOLTZ, P. O.	U. S. Electric Power and Light Co., Holliday and Centre Sts., Baltimore, Md.	Mar. 21, 1893
KELLER, E. E.	Vice-Prest. and General Manager, Westinghouse Machine Co , 224 Murtland Ave., Pittsburg, Pa.	Sept. 20, 1893

Name.	Address.	Date of Election.
Keller, Edwin R., *M.E.*	Mechanical and Electrical Engineer, Falkenau Engineering Co., Ltd., 727 Reading Terminal, 4823 Springfield Ave., Philadelphia, Pa.	Mar. 21, 1894
Kellogg, James W., *M.E.*	General Electric Co., Lighting Dept., Schenectady, N. Y.	June 26, 1891
Kelly, William F.	Manufacturers' Electric Co., American and Somerset Sts., Philadelphia, Pa.	Mar. 24, 1897
Kenan, Wm. R. Jr.	Chemist and Electrical Engineer, Lake Superior Carbide Works, Sault Ste., Marie, Mich.	Jan. 20, 1897
Kennelly, Arthur E. [Life Member.]	(*Manager.*) Electrician, Firm of Houston & Kennelly, Crozer Bldg., 1420 Chestnut St.; residence, The Landsowne, 41st St. and Elm Ave., Philadelphia, Pa.	May 1, 1888
Ker, W. Wallace	Instructor of Electricity, Hebrew Technical Institute, 36 Stuyvesant St., New York City. Residence, 43 Waverly St., Jersey City, N. J.	Sept. 25, 1895
King, Vincent C., Jr.	With V. C. & C. V. King, 517 West St.; residence, 110 East 16th Street, New York.	Aug. 5, 1896
Kinsley, Carl	Teacher of Electrical Engineering, Washington University, St. Louis, Mo.	May 18, 1897
Kirkegaard, Georg	Mechanical and Electrical Engineer, 28 State Street, New York City; residence, Giffords, Staten Island, N. Y.	Sept. 20, 1893
Kirkland, John W.	Electrical Engineer, General Electric Co., Schenectady, N. Y.	Mar. 21, 1894
Kittler, Dr. Erasmus	Professor at the Technical High School, Darmstadt, Germany.	Dec. 16, 1896
Klauder, Rudolph H.	Electrical Engineer, The Electric Storage Battery Co., Philadelphia, Pa.	Aug. 13, 1897
Klinck, J. Henry	Dept. Electrical Engineering, Lehigh University, South Bethlehem, Pa.	Jan. 16, 1895
Knox, Frank H.	Charleston City Railway Co., 58 Broad St., Charleston, S. C.	June 20, 1894
Knox, Geo. W.	Electrical Engineer, Chicago City Railway Co., 2020 State St., Chicago, Ill.	Nov. 18, 1896
Knox, James Mason	Student in Electrical Engineering, Columbia University, School of Mines; residence, 32 West 129th St., New York City.	Jan. 17, 1894
Kreidler, W. A.	Editor and Publisher, *Western Electrician*, 510 Marquette Building, Chicago, Ill.	Oct. 4, 1887
Labouisse, John Peter *M.E.*	40 Park St., Lynn, Mass.	Aug. 5, 1896

Name.	Address.	Date of Election.
Lamb, Richard	Chief Engineer, in charge business of the Lamb Electrical Cableways, The Trenton Iron Co., No. 1 Broadway, New York City.	Dec. 18, 1895
Land, Frank	The Hamilton, E. Genesee Street, Syracuse, N. Y.	Sept. 22, 1891
Lane, Vance	Manager and Superintendent Construction, Nebraska Telephone Co., Omaha, Neb.	Dec. 19, 1894
Lanphear, Burton S.	Instructor in Electrical Engineering, Maine State College, Orono, Me.	Jan. 16, 1895
Lanman, William H.	Board of Patent Control, 120 Broadway, New York City.	June 6, 1893
Lardner, Henry Ackley	Borough of Manhattan Electric Co., 33 Gold St., New York City.	Dec. 19, 1894
Larned, Sherwood J.	Electrical Engineer, Chicago Telephone Co., 203 Washington St., Chicago, Ill.	Oct. 17, 1894
Larrabee, Rollin N.	Western Electric Co., 242 Jefferson St., Chicago, Ill.	Mar. 20, 1895
Latham Harry Milton	In Engineering Department, American Bell Telephone Co., 42 Farnsworth St., South Boston, Mass.	Dec. 16, 1896
LeBlanc, Charles	Ingenieur en Chef, de la Compagine Generale de Traction, 24 Boulevard des Capucines, Paris, France.	April 17, 1895
LeClear, Gifford,	Electrical and Mechanical Engineer, Partner Densmore & Le Clear, 7 Exchange Place, Boston, Mass.; residence, Cambridge, Mass.	Oct. 27, 1897
LeConte, Joseph Nisbet	Instructor in Electrical Engineering, State University, Berkeley, Cal.	Feb. 27, 1895
Ledoux, A. R., *M. S.*, *Ph.D.*,	9 Cliff St., New York City.	Dec. 7, 1886
Lee, John C.	Chemist and Electrician, American Bell Telephone Co., Mountfort St., Longwood, Brookline, Mass.	Mar. 18, 1890
Lemon, Charles,	Hon. Sec'y for New Zealand for the Institution of Electrical Engineers, Palmerston, North, New Zealand.	Jan. 22, 1896
Lenz, Karl	Draughtsman, Brooklyn Union Gas Co., 97 2nd Ave., New York City.	May 19, 1896
Lenz, Charles Otto	Electrical Engineer, 150, Camp Street, Providence, R. I.	Mar. 15, 1892
Le Pontois, Leon.	Electrical Engineer, The Westinghouse Elec. and Mfg. Co., Pittsburg, Pa.	Dec. 18, 1895
Levy, Arthur B.	Assistant Engineer, Arc Light Dept., General Electric Co., 810 Lexington Ave., New York City.	Jan. 20, 1891
Lewis, Henry Frederick William,	Redlands, 48 Sydenham Road, Croydon, Surrey, England.	Mar. 5, 1889
Libby, Samuel Byington	Supt. N. Y. & S. I. Electric Co., West New Brighton, N. Y.	Feb. 23, 1898

Name.	Address.	Date of Election.
LILLEY, L. G.	Electrical Inspector, Underwriters' Association of Cincinnati, S. W. Cor. 3d and Walnut Sts , Cincinnati, O.; residence, Wyoming, O.	June 20, 1894
LINCOLN, PAUL M.	Electrician-in-charge, Cataract Construction Co., Niagara Falls, N. Y.	Sept. 25, 1895
LINDNER, CHAS. T.	Martin & Lindner, Electrical Engineers, Luning Building, San Francisco, Cal., residence, Berkeley, Cal.	Dec. 20, 1893
LINDSAY, WM. E.	Chief Engineer and Master Mechanic for Swift & Co., South Omaha, Neb.	April 17, 1895
LITTLE, C. W. G.	Engineer, British Thomson-Houston Co., 83 Cannon Street, London, Eng.	April 22, 1896
LOEWENHERZ, HERMAN	Electrical and Mechanical Engineer, 1376 Lexington Ave., New York City,	Feb. 27, 1895
LORIMER, GEO. WM.	Superintendent of Construction, The Callender Telephone Exchange Co., Troy, O.	Aug. 5, 1896
LORIMER, JAMES HOYT	Electrical Engineer. The Callender Telephone Exchange Co., Troy, O.	Aug. 5, 1896
LOUIS, OTTO T.	Manager of New York Branch, Queen & Co., Inc.; residence, 340 East 119th St., New York City.	Feb. 23, 1898
LOVEJOY, D. R.	Assistant in Electrical Engineering, Columbia University; residence, 222 East 49th St., New York, N. Y.	April 28, 1897
LOW, GEORGE P.	Editor and Proprietor, *Journal of Electricity*, 22 Clay St., San Francisco, Cal.	Jan. 17, 1893
LOZIER, ROBERT T. E.	Electrical Engineer, Member of Firm of Bullock Electric Co., St. Paul Bldg., New York City.	May 20, 1890
LUDLAM, HARRY W.	With Western Electric Co., 57 Bethune St., New York City.	Dec. 18, 1895
LUNDELL, ROBERT	Electrical Engineer, Interior Conduit and Insulation Co., 527 W. 34th St., New York; residence, 47 Brevoort Pl., Brooklyn, N. Y.	Feb. 7, 1890
LUQUER, THATCHER, T. P.	New York Telephone Co., 18 Cortlandt St., residence, Bedford, N. Y.	June 26, 1891
LYMAN, CHESTER WOLCOTT, *M. A.*	Manager Herkimer Paper, Co., Herkimer, N. Y.	Sept. 19, 1894
LYMAN, JAMES [Life Member.]	839 Union Street, Schenectady, N. Y.	Sept. 19, 1894
MACCOUN, ELLICOTT	Supt. of the Electrical Dep't., The Carnegie Steel Co., Braddock, Pa.	Nov. 20, 1895
MACCULLOCH, ROBERT C.	Manager, Jos. Lough Electric Co., 503 Fifth Ave.; residence, 209 W. 81st St., New York City.	Feb. 27, 1895
MACFADDEN, CARL K.	Electrical Engineer, Gas Engine Dep't Western Gas Construction Co., Fort Wayne, Ind.	Sept. 27, 1892

Name.	Address.	Date of Election.
MacGregor, Willard H.	With Ward Leonard Electric Co., Hoboken, N. J.; residence, 359 W. 27th St., New York City.	Jan. 20, 1897
Mackie, C. P.	30 Broad St., New York City; residence, Englewood, N. J.	Mar. 21, 1893
Mackintosh, Fred'k.	Electrical Engineer, General Electric Co.; residence, 225 Union St., Schenectady, N. Y.	Mar. 25, 1896
MacLeod, George	Superintendent and Engineer, Kentucky and Indiana Bridge Co., 29th and High Sts., Louisville Ky.; residence, New Albany, Ind.	Aug. 5, 1896
MacMullan, Robert Heath,	Lafayette, Ind.	Sept. 22, 1891
Madden, Oscar E.	[Address unknown.]	April 15, 1884
Magee, Louis J.	Electrical Engineer, Director, der Union Elektricitats Gesellschaft, Corneliusstr 1., Berlin, W. Germany.	April 2, 1889
Maki, Heiichir	Chief Engineer, Kioto Traction Co., Suyemarucho Dotemachi Marutamachisagarn, Kioto, Japan.	Aug. 5, 1896
Malia, James P.	Electrician, Armour & Co., 5316 Union Ave., Chicago, Ill.	June 20, 1894
Mann, Francis P.	[Address unknown.]	June 6, 1893
Manson, Jas. W.	[Address unknown.]	Mar. 25, 1896
Martin, Frank	Electrical Engineer, c/o Appert Glass Co., Port Alleghany, Pa.	Oct. 21, 1890
Martin, James A.	[Address Unknown.]	May 19, 1896
Martin, T. Commerford	(*Past-President.*) Editor, *The Electrical Engineer*, 120 Liberty Street, New York City.	April 15, 1884
Mason, James H.	Electrical Expert, 10 Fifth Ave., Brooklyn, N. Y.	May 19, 1891
Mather, Eugene Holmes	Central Railway and Electric Company, New Britain, Conn.	April 28, 1897
Matthews, Charles P.	Associate Professor, Electrical Engineering, Purdue University, Lafayette, Ind.	May 16, 1893
Maxwell, Eugene	225 N. Wasatch St., Colorado Springs, Col.	Aug. 5, 1896
Mauro, Philip	Counsellor at-Law in Patent Causes (Pollock & Mauro), 620 F. St., Washington, D. C.	Dec. 21, 1892
Mayer, Maxwell M.	Mfr. of Plating Dynamos, 2d Ave. and 121st St.; residence 433 East 116th St., New York City.	Feb. 27, 1895
Mayrhofer, Jos. Carl	Electrical Engineer, 165 W. 82d St., New York City.	June 20, 1894

Name.	Address.	Date of Election.
McBride, James	Superintendent, N. Y. & Boston Dye Wood Co., 146 Kent St., Brooklyn, N. Y.	Sept. 27, 1892
McCarthy, E. D.	Electrical Engineer, The F. P. Little Electric Construction and Supply Co., 135 Seneca St.; residence, 451 14th Street, Buffalo, N. Y.	Nov. 18, 1896
McCluer, Chas. P.	District Inspector, So. Bell Tel. and Tel. Co., Richmond, Va.	Apr. 22, 1896
McClurg, W. A.	Manager, Electrical Dept., Plainfield Gas and Electric Light Co., 207 Madison Ave., Plainfield, N. J.	Dec. 20, 1893
McElroy, James F.	Mechanical Supt., The Consolidated Car Heating Co., 131 Lake Ave., Albany, N. Y.	Nov. 15, 1892
McKay, C. R.	Consulting Engineer, 140 South Main St., Salt Lake City, Utah.	Dec. 20, 1893
McKibbin, George N.	Reed & McKibbin, General Street Railway Contractors, 30 Broad St., New York City.	June 8, 1887
McKissick, A. F.	Professor of Electrical Engineering, The A. & M. College of Ala., Auburn, Ala.	Feb. 16, 1892
McRae, Austin Lee	Consulting Electrical Engineer, 306 Oriel Bldg , St. Louis, Mo.	May 17, 1892
Meadows, Harold Gregory	Associate Engineer (Elec.) with Newcomb Carlton, 109 White Building; residence, 114 West Chippewa St., Buffalo, N. Y.	Sept. 23, 1896
Medina, Frank P.	Electrician, Pacific Postal Telegraph Co., 534 Market St., San Francisco, Cal.	Sept. 19, 1894
Meredith, Wynn	Electrical Engineer, Hasson & Hunt, 310 Pine St., San Francisco, Cal.	Jan. 17, 1894
Merrill, E. A.	Electrical Engineer, MacIntosh and Seymour, 26 Cortlandt St., New York City.	Sept. 20, 1893
Merrill, Josiah L.	Electrical Engineer, St. Johnsbury, Vt.	Sept. 25, 1895
Merritt, Ernest	Assistant Professor in Physics, Cornell University, Ithaca, N. Y.	Sept. 16, 1890
Merz, Chas. H.	British Thomson-Houston Ltd., 38 Parliament St., London, S.W.; residence, The Quarries, Newcastle-on-Tyne, England.	Sept. 25, 1895
Meyer, Julius	Consulting Engineer, 55 Broadway, New York City.	Oct. 25, 1892
Middlemiss, P. R., *M. E.*	Electrical Engineer, General Electric Co., Box 588, Schenectady, N. Y.	Mar. 20, 1895
Miller, Wm. C., *M. S.*	Electrical Engineer, 3 South Hawk St., Albany, N. Y.	Oct. 21, 1890
Miner, Willard M.	Electrician and Inventor, 428 East Sixth St., Plainfield, N. J.	July 12, 1887

Name.	Address.	Date of Election.
Mitchell, Sidney Z.	Manager, Oregon, Washington and Idaho Agency, General Electric Co., Fleischner Building, Portland, Ore.	Nov. 12, 1889
Mole, Harvey Edward	Ass't in Engineering Dept. J. G White & Co., 29 Broadway; residence, 320 West 58th St., New York City.	Nov. 30, 1897
Moore, Wm. E.	General Superintendent, The Augusta Railway & Electric Co., Augusta, Ga.	Jan. 22, 1896
Monell, Joseph T.	Consulting Electrical Engineer, 236 W 22d St., New York City.	Oct. 27, 1891
Montague, Ralph L.	Chief of Electrical Department, The Gold Dredging Co., Bannack, Mont.	Feb. 26, 1896
Mora, Mariano Luis	General Electric Co., 44 Broad St., New York City.	Mar. 20, 1895
Mordey, Wm. Morris	Electrician, Brush Electrical Engineering Co., Princes Mansions, Victoria St., Westminster, London, Eng.	Sept. 22, 1891
Morgan, Chas. H.	Southern Bell Telephone and Telegraph Co., Richmond, Va.	Aug. 5, 1896
Morgan, Jacque L.	Electrical Inspector, Kansas City Fire Dep't.; residence, 1702 Locust St., Kansas City, Mo.	Jan. 26, 1898
Morehouse, H. H.	Morehouse and Morrell, General Electric Installation and Contracting Work, Apartado, No 44, Quezaltenango, Guatemala, C. A.	Feb. 21, 1894
Morley, Edgar L.	Sup't Hatzel & Buehler, 114 5th Ave., New York City.	Sept. 25, 1895
Morrison, J. Frank	15 South St., Baltimore, Md.	April 15, 1884
Morse, George H.	Wagner Electric Mfg. Co. St. Louis, Mo.	May 15, 1894
Morss, Everett	Vice-President, Simplex Electric Co., 303 Marlboro St., Boston, Mass.	Sept. 22, 1891
Mortland, James A.	Prof. of Physics, Faculty State Normal School, 2502 Walnut St., Cedar Falls, Iowa.	Feb. 23, 1898
Morton, Henry, *Ph.D.*	President of Stevens Institute of Technology, Hoboken, N. J.	May 24, 1887
Moses, Dr. Otto A.	Electrician, 1037 Fifth Ave., New York City.	May 17, 1887
Moses, Percival Robert, *E. E.*	Electrical Engineer, and Contractor, 35 Nassau St.: residence, 46 West 97th St., New York City.	Dec. 19, 1894
Mosman, Chas. T.	Power and Mining Engineering Dep't., General Electric Co.; residence, 406 Union St., Schenectady, N. Y.	Mar. 20, 1895
Mosscrop, Wm. A., *M.E*	Electrical Engineer, 189 Montague St., Brooklyn, N. Y.	May 7, 1889
Munns, Chas. K.	Cedar Falls, Iowa.	Nov. 21, 1894
Myers, L. E.	Secretary and Treasurer, Electrical Installation Co., 917 Monadnock Building, Chicago, Ill.	Sept. 19, 1894
Neilson, John	Sup't. of Interior Wiring Department, Larchmont Electric Co., Larchmont, N. Y.	May 18, 1897

Name.	Address.	Date of Election.
Newbury, F. J.	Manager Insulated Wire Department, John A. Roebling's Sons Co., Trenton, N. J.	Sept. 23, 1896
Nicholson, Walter W.	General Supt. Central N. Y. Telephone and Telegraph Co., Telephone Building, Syracuse, N. Y.	May 15, 1894
Nimis, Albert A.	Assistant Electrician, B. Altman & Co.; residence, 175 3rd Ave. New York.	Aug. 13, 1897
Nock, Geo. W.	Chief Engineer, in charge of Steam and Electric Plant Westinghouse Elect. and Mfg. Co., Pittsburg, Pa.	Aug. 5, 1896
Norton, Elbert F.	With Card Electric Motor and Dynamo Co., 622-3 Western Union Building, Chicago, Ill.	Dec. 20, 1893
Noxon, C. Per Lee	Contracting Electrical Engineer, 504 Townsend St., Syracuse, N. Y.	Oct. 17, 1894
Nunn, Richard J., *M.D.*	Physician, 119½ York St., Savannah, Ga.	July 12, 1887
Nyhan, J. T.	Superintendent and Electrician, Macon and Indian Spring Electric Railway, Macon, Ga.	Feb. 27, 1895
Ockershausen, H. A.	Electrical Engineer, 65 Madison Ave., Jersey City, N. J.	Sept. 6, 1887
Olan, Theodor, J. W.	Civil and Electrical Engineer, 68 West 49th St., New York City.	May 16, 1893
Olivetti, Camillo	Ingegnere Industriale, Ivrea, Italy.	Oct. 17, 1894
Ormsbee, Alex. F.	Electrical Engineer; residence, 183 Joralemon St., Brooklyn, N. Y.	June 27, 1895
Osborne, Loyall Allen	Assistant to 2nd Vice-President Westinghouse Electric and Mfg. Co., Pittsburg, Pa.	Oct. 18, 1893
Osterberg, Max, *E.E., A.M.*	Consulting Engineer, and Electrical Expert, Bowling Green Building, New York City.	Jan. 17, 1894
O'Sullivan, M. J.	Superintendent, Electric Light, B. & O. R. R. Co., 154 Keen Street, Zanesville, O.	Mar. 20, 1895
Otten, Dr. Jan D.	Director, Batavia Electrische Tram-Maatschappij, Van Baerlstraat 80, Amsterdam, Holland.	Nov. 18, 1890
Page, A. D.	Assistant Manager, General Electric Co. Lamp Works, Harrison, N. J.	Jan. 19, 1892
Parcelle, Albert L.	Electrician and Inventor, 157 Washington St., Boston, Mass.	Dec. 16, 1891
Parker, Herschel C.	Tutor in Physics, Columbia University, 21 Fort Green Pl., Brooklyn, N. Y.	April 19, 1892
Parmly C. Howard, *S.M.*, *E.E.*	College of the City of New York, 17 Lexington Ave.; residence, 344 W. 29th St., New York City.	Feb. 21, 1893

Name.	Address.	Date of Election.
Parry, Evan	Engineer, The British Thomson-Houston Ltd., Sunningdale, Fitzgerald Ave., Barnes, London, Eng.	Sept. 25, 1895
Parsell, Henry V. A., Jr.	31 E. 21st St., New York City.	Nov. 12, 1889
Patton, Percy I.	Sheble & Patton, Ltd., 1020 Filbert St.; residence, The Bartram, 33d and Chestnut St., Philadelphia, Pa.	Mar. 20, 1895
Peck, Edward F.	15 Cortlandt Street, New York City; residence, 825 Park Place, Brooklyn, N. Y.	May 20, 1890
Peckham, W. C.	Prof. of Physics, Adelphi College, Brooklyn; residence, 406 Classon Ave., Brooklyn, N. Y.	Nov. 30, 1897
Pedersen, Frederick Malling	Assistant Electrical Engineer, Crocker-Wheeler Electric Co., 39 Cortlandt St., residence, 39 Washington Square, New York City.	Sept. 20, 1893
Peirce, Arthur W. K.	Simmer and Jack Gold Mining Co., Johannesburg, S. A. R.	June 27, 1895
Perkins, Frank C.	Electrical Engineer and Contractor, 774 Prospect Ave., Buffalo, N. Y.	Oct. 21, 1890
Petty, Walter M.	Superintendent Fire Alarm Telegraph, Rutherford, N. J.	May 16, 1893
Pfund, Richard	With Western Union Telegraph Co., 195 Broadway, New York City.	April 18, 1893
Phelps, Wm. J.	Electrical Engineer and Contractor, Monadnock Bldg., Chicago; residence, Elmwood, Ill.	Mar. 25, 1896
Philbrick, B. W.	Electrician, in charge of Electrical Plant, Hon. Levi P. Morton, Rhinecliff, N. Y.	May 15, 1894
Phillips, Eugene F.	President, American Electrical Works, Phillipsdale, R. I.	July 13, 1889
Phillips, Leo A.	Superintendent, Flushing Electric Light and Power Co., 50 Lawrence St., Flushing, N. Y.	Mar. 21, 1894
Phillebre, Fred'k William	Stanley Electric Mfg. Co., Pittsfield, Mass.	Nov. 20, 1895
Pillsbury, Chas. L.	City Electrical Inspector, City Hall; residence, 1100 Hawthorne Ave., Minneapolis, Minn.	Aug. 13, 1897
Pinkerton, Andrew	Electrical Engineer, The Apollo Iron and Steel Co., Apollo, Pa.	Sept. 25, 1895
Plumb, Charles	Proprietor and Electrician, The Chas. Plumb Electrical Works, 70 West Swan St., Buffalo, N. Y.	June 20, 1894
Poole, Cecil P.	55 New Street; residence, 206 W. 80th St., New York City.	Jan. 3, 1888
Pope, Ralph Wainwright	Secretary to the American Institute of Electrical Engineers, 26 Cortlandt St., (Telephone, 2199 Cortlandt), New York City; residence, 570 Cherry St., Elizabeth, N. J.	June 2, 1885

Name.	Address.	Date of Election.
Porter, H. Hobart, Jr.	Agent, Westinghouse Elec. and Mfg. Co., 120 Broadway, New York; residence, Lawrence, L. I.	Mar. 25, 1896
Potter, Henry Noel	[Address unknown.]	Sept. 19, 1894
Powell, Percy Howard	Construction Dep't. New York Telephone Co., 18 Cortlandt St., New York City; residence, Hempstead, N. Y.	Sept. 25, 1895
Price, Chas. W.	Editor the *Electrical Review*, Times Building, New York City; residence, 223 Garfield Place, Brooklyn, N. Y.	Sept 19, 1894
Price, Edgar F.	Electricial Engineer, Carbide Works, Niagara Falls, N, Y.	June 27, 1895
Prince, J. Lloyd	868 Flatbush Ave., (Flatbush Station), Brooklyn, N. Y.	Feb. 27, 1895
Privat, Louis	Electrician, Cicero Water, Gas and Electric Light Co., Oak Park, Ill.	Dec. 19, 1894
Proctor, Thos. L.	General Manager, Riker Electric Motor Co., Brooklyn; residence, Newtown, L. I., N. Y.	April 18, 1894
Prosser, Herman A.	Electrician, Baltimore Copper Smelting and Refining Co., Keyser Bldg.; residence, 1222 Madison Avenue, Baltimore, Md.	Jan. 26, 1898
Pupin, Dr. Michael I.	(*Vice-President*) Adjunct Professor in Mechanics, Columbia University; residence, 7 Highland Place, Yonkers N. Y.	Mar. 18, 1890
Ralston, Louis C.	10 N. Church St., Schenectady, N Y.	April 28, 1897
Randall, John E.	Columbia Incandescent Lamp Co., 1912 Olive St., St. Louis, Mo.	May 7, 1889
Randolph, L. S.	Professor of Mechanical Engineering, Blacksburg, Va.	Feb. 21, 1893
Rathenau, Erich	Electrical Engineer, Allg. Electricitats Gesellschaft, Berlin, Germany.	Nov. 20, 1895
Ray, William D.	General Manager Everett Railway and Electric Co., Everett, Washington.	Sept. 27, 1892
Read, Robert H.	Patent Attorney, 44 Broad St., New York City.	Jan. 19, 1892
Redman, Geo. A.	General Supt., Electric Dept., Brush Elec. Light Co., and Rochester Gas and Elec. Co., Rochester, N. Y.	Feb. 27, 1895
Reed, Chas. J.	Electrician, 3313 N. 16th St., Philadelphia, Pa.	Mar. 5, 1889
Reed, Harry D.	Electrician, Bishop Gutta Percha Co., 420 East 25th St., New York City; residence, 88 North 9th St., Newark, N. J,	Sept. 19, 1894
Reed, Henry A.	Secretary and Manager, Bishop Gutta-Percha Co., 422 East 25th St., New York City; residence, 88 North 9th St., Newark, N. J.	June 4, 1889
Reid, Edwin S.	General Sup't of Construction, National Underground Cable Co., 17 Times Building; residence, 116 W. 11th St., New York City	Feb. 26, 1896

Name.	Address.	Date of Election.
Reid, Thorburn	Consulting Electrical Engineer, 120 Liberty St., New York City.	Oct. 21, 1890
Reilly, John C.	General Supt., N. Y. & N. J. Tel. Co., 16 Smith St., Brooklyn, N. Y.	April 15, 1884
Rennard, John Clifford,	*A. B. E. E.* Consulting and Supervising Electrical Engineer, 15 Dey St., New York City.	Jan. 16, 1895
Requier, A. Marcel	Electrical Engineer, Westinghouse Electric Co., (L't'd.) 32 Victoria St., London, S. W. Eng.	Dec. 20, 1893
Rhodes, S. Arthur	Electrician, Chief Testing Department, Chicago Telephone Co, Chicago, Ill.; residence, 429 North Pine Ave., Austin, Ill.	Oct. 17, 1894
Rice, Arthur L.	Professor of Steam and Electrical Engineering, Pratt Institute, Brooklyn, N. Y.	Oct. 21, 1896
Rich, Francis Arthur	Consulting Mining and Electrical Engineer, 314 Victoria Arcade, Auckland, New Zealand.	Jan. 20, 1897
Richards, Chas. W.	C. W. Richards & Co, 64 Federal St, Boston; residence, Needham, Mass.	Sept. 23, 1896
Richardson, Robert E.	Electrical Engineer, Pierce & Richardson, 1409 Manhattan Building; residence, 3622 Calumet Ave, Chicago, Ill.	Sept. 19, 1894
Richey, Albert S.	Electrician, Citizens' Street Railway Co., 403 W. Adams Street, Muncie, Ind.	May 18. 1897
Ricker, Charles W.	Expert Electrical Engineer, 184 Cleveland Ave., Buffalo, N. Y.	May 15, 1894
Rideout, Alexander C.	*LL. D.*, Consulting Electrical and Mechanical Engineer, 101 Randolph St., Chicago, Ill.	Aug. 5, 1896
Ridley, A. E. Brooke	Agent, Electrical Engineer, Siemens & Halske Electric Co., 10 Front St., San Francisco, Cal.	Nov. 21, 1894
Ripley, Wm. Howe	605 Lexington Avenue, New York City.	Feb. 17, 1897
Rittenhouse, Chas. T.	247 W. 138th St, New York City.	Feb. 21, 1894
Roberson, Oliver R.	Electrician, Western Union Telegraph Co., 195 Broadway, P. O. Box 856, New York City.	Dec. 20, 1893
Robinson, Almon	Draughtsman, Expert in Methods of Gearing, Webster Road, P. O. Box 943, Lewiston, Me.	Sept. 6, 1887
Robinson, Dwight Parker	Manager, Edison Illuminating Co., 15 South St., Baltimore, Md.	Sept. 25, 1895
Robinson, Francis G.	With Brooklyn Heights R. R. Co.; residence, 156 Macon St., Brooklyn, N. Y.	Nov. 21, 1894

Name.	Address.	Date of Election.
Rodman, Samuel, Jr.	(Late 1st Lieut., 2nd U. S. Artillery), Electrician and Expert in High Explosives. Room 106, Pullman, Bldg., Chicago, Ill.	Sept. 16, 1890
Roebling, Ferdinand W.	Manufacturer of Electrical Wires and Cables, Trenton, N. J.	June 8, 1887
Roller, Frank W. *M.E.*	Electrical Engineer, Machado & Roller, Electrical Machinery, 203 Broadway, N. Y.; residence, Cranford, N. J.	May 21, 1895
Roper, Denney W.	Edison Illuminating Co. of St. Louis, Mo., Alton, Ill.	June 6, 1893
Rosa. Edward B.	Professor of Physics. Wesleyan University, Middletown, Conn.	Feb. 17, 1897
Rosebrugh, Thomas Reeve	Lecturer in Electrical Engineering, School of Practical Science, Toronto, Ont.	June 26, 1891
Rosenbaum, Wm. A.	Electrical Expert and Patent Solicitor, 177 Times Building, New York City.	Jan. 3, 1889
Rosenberg, E. M., *M. E.*	Residence, 138 W. 85th St., New York City.	Oct. 21, 1890
Ross, Taylor William	Second Assistant Engineer, U. S. Revenue Cutter Service, Revenue Cutter "Perry," Astoria, Or.	Mar. 25, 1896
Rowland, Arthur John	Professor of Electrical Engineering, Drexel Institute; residence, 3220 Spencer Terrace, Philadelphia, Pa.	Sept. 19, 1894
Rowland, Henry A.	Professor of Physics, Johns Hopkins University, Baltimore, Md.	Mar. 21, 1894
Royce, Fred W.	Electrician and Patent Solicitor, 1423 New York Ave., Washington, D. C.	April 15, 1884
Rushmore, David B.	Foreman, Testing Dep't Royal Electric Co., Montreal, P. Q.	Sept. 25, 1895
Rutherford, Walter	Manager Electric Traction Dep't, Dick Kerr & Co., Ltd., London E. C., England.	Sept. 22, 1891
Sackett, Ward M.	Assistant Chief Draughtsman, Chicago Telephone Co., residence 3739 Ellis Ave., Chicago, Ill.	Oct. 17, 1894
Sage, Henry Judson	Sage & Co., Electrical Engineers, Rochester, Pa.	Dec. 20, 1893
Sahulka, Dr. Johann	Docent of Electrotechnics, Technische Hochschule, Vienna, Austria.	Dec. 20, 1893
Sanborn, Francis N.	Torrington, Conn.	Nov. 24, 1891
Sanderson, Edwin N.	Of Sanderson & Porter, Engineers and Contractors, 120 Broadway, New York City.	Oct. 17, 1894
Sargent, Howard R.	Electrical Engineer, General Electric Co.; residence, 242 Union Street, Schenectady, N. Y.	Mar. 25, 1896

Name.	Address.	Date of Election.
BERG, CARL HUGO	Chief Engineer. The Midvale Steel Co., Nicetown, Phila., Pa.; residence 1752 N. 26th St., Philadelphia, Pa.	Aug. 5, 1896
, FRED. W.	68 Mount Vernon St., Fitchburg, Mass.	June 27, 1895
Y, FREDERICK	Electrical Engineer, 288 Summer Ave., Newark, N. J.	June 5, 1888
LE, ALBERT	Manager for George Cutter, 851 The Rookery, Chicago, Ill.	June 20, 1894
SER, FRED. G.	Superintendent of Electric Dept , Laclede Gas Light Co., 411 N. 11th St. Louis, Mo.	Sept. 22, 1891
TER, HEINR. *C. E.*	Counsellor and Attorney, 20 Nassau St , New York City.	Jan. 17, 1893
, CHAS. H.	Electrical Engineer, Ideal Electric Corp., 216 Third Ave., New York City.	Feb, 23, 1898
B, MARTIN C.	1729 Madison Ave., Baltimore, Md.	Nov. 18, 1896
BE, WALTER P.	Electrician, Rutherford, Boiling Springs and Carlstadt Electric Co., Carlstadt, N. J.	May 19, 1896
RE, FRANK L.	With N. Y. C. & H. R. R. R. Co., office of A. F. A.; residence, 2059 Anthony Ave., New York City.	Dec. 18, 1895
, JAMES B.	Electrical and Mechanical Engineer, 227 East German St., Baltimore Md.	Aug. 5, 1896
, WM. M.	Electrical Engineer. The Cutter Electrical and Mfg. Co., 1112 Sansom St., Philadelphia, Pa.; residence, 108 West Johnson St , Germantown, Pa.	June 23, 1897
NG, LEWIS	Consulting, Mechanical, and Electrical Engineer, Denver Engineering Works, Denver, Col.	April 3, 1888
ES, A. L.	Engineering Dept., Fort Wayne Electric Corporation, Fort Wayne, Ind.	April 18, 1894
WICK, C. E	Agent at San Francisco Office, General Electric Co , 15 First St.; residence, Berkeley, Cal.	Feb. 23, 1898
A. B.	A. B. See Manufacturing Co., 116 Front St.; residence, 107 East 19th St , (Flatbush), Brooklyn, N. Y.	Jan. 17, 1893
Y, J. A.	Electrical Engineer and Contractor, 121 Liberty St., New York City.	April 15, 1884
INGER, HARRY M.	Consulting and Constructing Engineer, 6 Northampton St., Wilkes-Barre, Pa.	Sept. 20, 1893
ELL, LEMUEL WM.	Mechanical and Electrical Engineer, 99 Cedar St., New York City; residence, Plainfield, N. J.	Nov. 1, 1887
A, A. A	With Fort Wayne Electric Corporation, 17 Federal St., Boston, Mass.	Dec. 20, 1893
FNER, S. C.	Supt. and Electrician. Electric Lighting Co. of Mobile, Box, 234, Mobile, Ala.	Aug. 13, 1897
N, CHARLES D.	136 Liberty St., New York City.	June 7, 1892
RP, CLAYTON H.	Instructor, Department of Physics, Cornell University, 122 University Ave., Ithaca, N. Y.	May 15, 1894

Name.	Address.	Date of Election.
SHARPE, E. C.	Consulting Electrical Engineer, 524 S. Broadway, Los Angeles, Cal.	Feb. 26, 1896
SHAW, HOWARD BURTON	Assistant Professor Electrical Engineering, Missouri State University, Columbia, Mo.	April 28, 1897
SHEDD, JOHN C.	531 State St., Madison, Wisc.	Dec. 19, 1894
SHEEHY, ROBERT J.	President, Sheehy Automatic Railroad Signal Co., 122 Pearl St., Boston, Mass.	April 21, 1891
SHIELDS. W. J.	Consulting Engineer, New Wilmington, Pa.	Sept. 19, 1894
SHOCK, THOS. A. W.	Gen'l Sup't Portland General Electric Co., Portland, Or.	Mar. 20, 1895
SHONNARD, HAROLD W.	[Address unknown.]	Oct. 23. 1895
SIMPSON, ALEXANDER B.	Estimating Engineer, Western Electric Co., N. Y. City ; residence, 164 7th Ave., Whitestone, L. I.	May 21, 1891
SISE, CHARLES F.	President, Bell Telephone Co., of Canada, P. O. Box 1918, Montreal, Canada.	June 8, 1887
SKIRROW, JOHN F.	Ass't Manager, Postal Telegraph Cable Co., New York City; residence, 183 N. 19th St , East Orange, N. J.	Sept. 25, 1895
SLADE, ARTHUR J., *Ph.D.*	Engineer, with George Hill, 44 Broadway; residence, 62 East 66th St., New York City.	Sept. 19, 1894
SLATER, FREDERICK R.	Designing Department, Otis Bros. & Co., 153 Warburton Ave., Yonkers, N. Y.	Oct. 17, 1894
SMITH, CHARLES HENRY, JR.	Box 2, Atlanta, Ga.	Jan. 17, 1894
SMITH, FRANK E.	Chief Electrician, Edison Light and Power Co., 229 Stevenson St., San Francisco, Cal.	Sept 19, 1894
SMITH, FREDERICK H.	Civil Engineer, 216 Equitable Bldg., Baltimore. Md.	Nov. 12, 1889
SMITH, HAROLD BABBITT	Professor of Electrical Engineering, Worcester Polytechnic Institute; residence, Trowbridge Road, Worcester, Mass.	Nov. 24, 1891
SMITH, J. BRODIE	Supt. and Electrician, Manchester Electric Light Co., 142 Merrimack St., Manchester, N. H.	Mar. 21, 1894
SMITH, J. ELLIOT	Superintendent Fire Alarm Telegraph, 122 W. 73d St., New York City.	April 15, 1884
SMITH, OBERLIN	President and Mechanical Engineer, Ferracute Machine Co., Lochwold, Bridgeton, N. J.	May 19, 1891
SMITH, T. JARRARD	Manufacturers and Inventors' Electric Co., 96 Fulton St., New York City; residence, Roselle, N. J.	April 19, 1892
SPEED, BUCKNER	Assistant Electrical Engineer, Louisville Electric Light Co., 1521 4th Street, Louisville, Ky.	Apr. 22, 1896

Name.	Address.	Date of Election.
SPENCER, PAUL	Gen'l Sup't, People's Light and Power Co., Newark, N. J.; residence, Montclair, N. J.	Nov. 30, 1897
SPENCER, THEODORE	With Bell Telephone Co., 406 Market St., Philadelphia, Pa.	Mar. 21, 1893
SPROUT, SIDNEY S.	Electrical Engineer, 328 Montgomery St., San Francisco, Cal.	Jan. 17, 1894
SQUIER, GEORGE O., *Ph.D.*	1st Lieut., 3d Artillery, Fortress Monroe, Va.	May 19, 1891
STADELMAN, WM. A.	Agent, Elwell-Parker Co., 26 Cortlandt St., New York City.	Feb. 7, 1890
STAHL, TH.	Creusot Works, Creusot, France.	Nov. 15, 1892
STAKES, D. FRANKLIN	Electrical Expert and Salesman, The Fort Wayne Electric Corporation, 101 The Bourse, Philadelphia, Pa.	Jan. 20, 1897
STANLEY, WILLIAM	Electrician, Pittsfield, Mass.	Dec. 6, 1887
STANTON, CHAS. H.	With C. H. & H. Stanton Electrical Contractors, 1517 Walnut St.; residence, 134 S. 3d St., Philadelphia, Pa.	Mar. 20, 1895
STEVENS, J. FRANKLIN	Manager, Keystone Electrical Instrument Co., 9th St. and Montgomery Ave.; residence, 1419 Walnut St., Philadelphia, Pa.	Sept. 19, 1894
STEWART, ROBERT STUART	Supt. of Lines, Public Lighting Commission, 440 Jefferson Ave., Detroit, Michigan.	Dec. 20, 1896
STEWART, W. M.	Wire Chief, New York Telephone Co., 18 Cortlandt Street, New York City; residence, 973 Amsterdam Ave., New York City.	Mar. 25, 1896
STINE, WILBUR M.	(*Vice-President.*) Director Electrical Dept., Armour Institute; residence, 635 W. 61st Street, Chicago, Ill.	May 15, 1894
STOCKBRIDGE, GEO. H.	Patent Attorney, 95 Nassau Street; residence, 2514 11th Ave, near 187th St., New York City.	May 24, 1887
STONE, CHARLES A.	With Firm of Stone & Webster, 4 P. O. Sq., Boston, Mass.	May 19, 1891
STONE, JOSEPH P.	Electrical Engineer, General Electric Co.; residence, 213 Liberty Street, Schenectady, N. Y.	Dec. 18, 1895
STORER, NORMAN W.	Electrical Engineer, Westinghouse Electric and Mfg. Co., residence, Amber Club, Pittsburg, Pa.	Dec. 18, 1895
STORRS, PROF. H. A.	Professor of Electrical Engineering, University of Vt., Burlington, Vt.	Mar. 21, 1893
STRATTON, ALEX.	Assistant Electrical Engineer, C. & C. Electric Co., Garwood N. J.; residence 120 W. 126th St., New York City.	Mar. 20, 1895
STRAUS, THEODORE	Electrical Eng., General Electric Co., Schenectady, N. Y.; residence, 1213 Linden Avenue, Baltimore, Md.	Nov. 18, 1896

Name.	Address.	Date of Election.
STRAUSS, HERMAN A.	Consulting Electrical Engineer and Electrical Expert, 54 Maiden Lane and 29 Liberty St; residence, Kingscourt, Madison Ave., and 87th St., New York.	Oct. 17, 1894
STRONG, FREDERICK G.	Box, 959, Hartford, Conn.	Oct. 27, 1891
STURTEVANT, CHARLES L.	Patent Attorney, Atlantic Building, Washington, D. C.	Dec. 20, 1893
SULLIVAN, EDWARD	Supt. Construction, Standard Underground Cable Co., 18 Cortlandt St., residence, 337 W. 18th Street, New York City.	Feb. 26, 1896
SUMMERS, LELAND L.	Electrical Engineer, 441 The Rookery, Chicago, Ill.	Feb. 16, 1892
SVENTORZETZKY, CAPT. LOUDOMIR	Military Engineering Academy, St. Petersburg, Russia.	Sept. 20, 1893
SWENSON, BERNARD VICTOR	Assistant Professor of Electrical Engineering, University of Illinois, Champaign, Ill.	Feb. 27, 1895
SWEET, HENRY N.	Chief of Patent Bureau, Thomson Electric Welding Co., 4 Spruce St , Boston, Mass.	May 20, 1890
SWOOPE, C. WALTON	Instructor, Electrical Engineering, Spring Garden Institute ; residence, 12 North 38th St., Philadelphia, Pa.	Jan. 26, 1898
SYKES, HENRY H.	Chief Engineer, Bell Telephone Co., of Mo., Telephone Bldg., St. Louis, Mo.	Oct. 18, 1893
TACHIHARA, JIN	Electrical Engineer, Mining Dep't, Mitsu Bishi Co., Tokio, Japan.	Jan. 26, 1898
TAIT, FRANK M.	Superintendent, Catasauqua Electric Light and Power Co. and Catasauqua Gas Co., 731 3d St., Catasauqua, Pa.	Sept. 19, 1894
TAPLEY, WALTER H.	Electrician in Government Printing Office, care of Public Printer, Washington, D. C.	Oct. 25, 1892
TEMPLE, WILLIAM CHASE	Mechanical and Electrical Engineer, Lewis Block, P. O. Box 800, Pittsburg, Pa.	May 3, 1887
TESLA, NIKOLA	Electrical Engineer and Inventor, 46 E. Houston St., The Gerlach, 53 W. 27th St., New York City.	June 5, 1888
THAYER, GEORGE LANGSTAFF	Manager, Belle Plaine Electric Light Co., Belle Plaine, Ia.	Aug. 5, 1896
THOMAS, ROBERT MCKEAN, *E. E.*	Assistant Chief Inspector, Bureau of Electrical Appliances, N. Y. Fire Dept.; residence, 135 Madison Ave., New York City.	April 22, 1896
THORDARSSON, CHESTER H.	Chicago Edison Co.; residence, 284 Rush St., Chicago, Ill.	Dec. 18, 1895
THRESHER, ALFRED A.	Electrical Engineer and Proprietor Thresher Electric Co., Dayton, O	April 22, 1896
THURBER, HOWARD F.	General Superintendent, New York Telephone Co., 18 Cortlandt Street, New York City; residence, 49 Sidney Place, Brooklyn, N. Y.	Mar. 25, 1896

Name.	Address.	Date of Election.
TOERRING, C., JR.	Electrical Engineer, Helios Electric Co., 3214 Arlington Avenue., Philadelphia, Pa.	April 18, 1894
TORCHIO, PHILIPPO	Engineering Dep't, The Edison Elec. Illuminating Co., 53 Duane Street, New York City.	June 27, 1895
TOWER, GEORGE A.	Electrical Engineer, The Sherwood Land Co., and The Jefferson Hotel Co., 704 E. Main St., Richmond, Va.	May 15, 1894
TOWNSEND, HENRY C.	Attorney and Expert in Electrical Cases, 5 Beekman St., New York City.	July 10, 1888
TOWNSEND, SAMUEL G. F.	Assistant in Electrical Engineering, Columbia University; residence, 131 Fifth Ave., New York City.	Jan. 20, 1897
TREADWELL, AUGUSTUS, JR.	Private Assistant, Polytechnic Institute, 488 3d St., Brooklyn, N. Y.	Feb. 21, 1894
TROTT, A. H. HARDY [Life Member.]	Beer, near Axminster, Devonshire, Eng.	Jan. 20, 1891
TUTTLE, GEORGE W.	Electrical Engineer, Sawyer-Man Electric Co., 510 W. 23d St.; residence, 328 W. 23d St., New York City.	Mar. 17, 1891
VAIL, THEO. N.	26 Cortlandt St., New York City.	April 15, 1884
VAN BUREN, GURDON C.	Electrician and Electrical Contractor, 84 Clinton Ave., Albany, N. Y.	Oct. 25, 1892
VANDEGRIFT, JAMES A.	Sawyer-Man Electric Company, 125 Robinson St., Allegheny, Pa.	Nov. 24, 1891
VANDERSLICE, G. HAMILTON	326 Penn Avenue. Pittsburg, Pa.	Dec. 19, 1894
VAN DEVENTER, CHRISTOPHER	Student, Columbia University; residence, 626 Lexington Ave, New York City.	Feb. 17, 1897
VAN VLECK, FRANK	President, Van Vleck Tramway Co., Wells Fargo Bldg., Los Angeles, Cal.	Nov. 16, 1886
VAN VLECK, JOHN FALCONER	Constructing Engineer, The Edison Electric and Illuminating Co. of New York; residence, Glenridge, N. J.	Aug. 5, 1896
VAN WYCK, PHILIP V. R., JR.	Plainfield, N. J.	April 21, 1891
VARLEY, THOMAS W.	Electrician, United Electric Light and Power Co., 210 Elizabeth St., New York City.	Sept. 19, 1894
VARNEY, WILLIAM WESLEY	Attorney at Law, Electrical Expert, 118 East Lexington St.; residence, 712 N. Carey St., Baltimore, Md.	Nov. 21, 1894
VENABLE, WM. MAYO	Electrical Inspector, Cincinnati Underwriters' Association; residence, 3649 Vineyard Place, Cincinnati, O.	Nov 30, 1897
VOIT, DR. ERNST	Professor of Electricity, Technical University, Schwanthalerstrasse, Munchen, Germany.	Mar. 21, 1894

Name.	Address.	Date of Election.
VOSMAER, ALEXANDER	Electrical, Mechanical, Chemical Engineer, Director Electrical Research Laboratory, Zijlweg, 49 Haarlem, Holland.	Nov. 18, 1896
WAGNER, EDWARD ANDREWS.	Electrician, 30 Eddy St., Ithaca, N. Y.	Jan. 22, 1896
WALKER, ARTHUR F.	Sup't and Electrical Engineer, Edison Light Co., Grand Rapids, Mich.	Oct. 23, 1895
WALLACE, CHAS. F.	Engineer, Stone and Webster, Boston, Mass.; residence, 62 Forest Street, Roxbury, Boston, Mass.	Nov. 18, 1896
WALLACE, WILLIAM	Washington, D. C.	April 15, 1884
WARDELL, GEORGE PHELPS	675 Marcy Ave., Brooklyn, N. Y.	Nov. 12, 1889
WARDLAW, GEORGE A.	[Address unknown.]	Jan. 17, 1894
WARING, RICHARD S.	Standard Underground Cable Co., 61 Westinghouse Bldg., Pittsburg, Pa.	April 15, 1884
WARNER, CHAS. H.	Consulting Electrical Engineer, Bowling Green Building, New York City.	Dec. 20, 1893
WARREN, ALDRED K.	Proprietor, A. K. Warren & Co., 451 Greenwich St., New York; residence New Brighton, N. Y.	Nov. 20, 1895
WASON, CHAS. W.	Electrical Engineer and Purchasing Agent, Cleveland Electric R. R. Co., 2069 Euclid Ave., Cleveland, O.	May 19, 1891
WATERS, EDWARD G.	General Electric Co., 44 Broad St., New York City.	Mar. 18, 1890
WATTS, H. FRANKLIN	Electrical Engineer and Contractor, 1467 N. 53d St., W. Philadelphia, Pa.	May 20, 1890
WEBB, HENRY STORRS	Instructor in Electrical Engineering, Lehigh University, South Bethlehem, Pa.	Nov. 20, 1895
WEBSTER, DR. ARTHUR G.	Assistant Professor of Physics, Clark University, 936 Main St., Worcester, Mass.	Jan. 19, 1892
WEBSTER, EDWIN S.	Firm of Stone & Webster, 4 P. O. Sq., Boston, Mass.	April 21, 1891
WEISE, WILL M. T.	Manager, Weise Bros., Library Building, Davenport, Iowa.	Aug. 13. 1897
WELLS, DANA CLEMMER	Assistant in Physics, Columbia University, New York; residence, 109 Willow St., Brooklyn, N. Y.	April 28, 1897
WENDLE, GEORGE E.	760 W. 4th St., Williamsport, Pa.	Feb. 21, 1894
WEST, JULIUS HENRIK	Engineer, Handjery St., 58 Friedenau, Berlin, Germany.	Sept. 20, 1893
WELLES, FRANCIS R.	Manufacturer, 46 Avenue de Breteuil, Paris, France.	Sept. 6, 1887
WHARTON, HUGH M.	Electrical Engineer, 69 Christopher St., Montclair, N. J.	May 15, 1894
WHITAKER, S. EDGAR	Electrical Engineer and Contractor, 58 Oliver St., Fitchburg, Mass.	Aug. 5, 1896

Name	Address.	Date of Election.
White, Chas. G.	Public Schools Sup't, and Instructor in Physics and Chemistry, Lake Linden, Mich.	Sept. 23, 1896
White, J. G.	J. G. White & Co., Electrical Engineers and Contractors, 29 Broadway, New York City.	April 2, 1889
White, Will F.	Electrical Engineer, Vice-President, New Omaha T.-H. Electric Light Co., 309 So. 13th St., Omaha, Neb.	Feb. 7, 1890
Whiting, Allen H.	Electrical Engineer, Riker Electric Motor Co., Brooklyn, N. Y.; residence, Stamford, Conn.	Nov. 18, 1896
Whitmore, W. G.	Electrical Engineer, General Electric Co., Edison Building, Box 3067, New York City.	Mar. 18, 1890
Whitney, Henry M. [Life Member.]	81 Milk St., Boston, Mass.	July 12, 1887
Wiederhold, Oscar	Electrical Engineer, Wiederhold & Stoeckel, 30 Cortlandt St., New York; residence, Summit, N. J.	Aug. 13, 1897
Wiese, Gustav Adolph	City Electrician of Alameda, 718 Haight Ave., Alameda, Cal.	Sept. 25, 1895
Wightman, Merle J.	Electrical Engineer, The Staten Island Midland Railway Co., Stapleton, N. Y.	Mar. 5, 1889
Wiley, Walter S.	Engineer, with the American Waterworks, 1107 No. 40th St., Omaha, Neb.	April 18, 1894
Wiley, Wm. H.	Scientific Expert, 53 E. 10th St., New York City.	Feb. 7, 1888
Williams, Arthur	General Inspector, The Edison Electric Illuminating Co., of New York; residence, 155 Linden Boulevard, Brooklyn, N. Y.	June 23, 1897
Williams, Charles Jr.	Electrician, 1 Arlington Street, East Somerville, Mass.	April 15, 1884
Williams, Geo. Henry	District Supt. The Edison & Swan United Electric Co., Ltd., 134 Royal Avenue; residence, Culmore, Glenburn Park, Belfast, Ireland.	Oct. 27, 1897
Williamson, G. DeWitt	Dobbs Ferry, N. Y.	April 18, 1893
Willis, Edward J.	Supt. Richmond Traction Co., Richmond, Va.	Nov. 30, 1897
Wilson, Chester P.	General Manager, Sioux City Traction Co., Sioux City, Mo.	Sep. 25, 1895
Winand, Paul A. N.	Engineer and Supt., Schleicher, Schumm & Co., 3200 Arch St., Philadelphia, Pa.	June 20, 1894
Winchester, Samuel B.	9 Laurel St., Holyoke, Mass.	May 15, 1894
Winslow, I. E.	The General Traction Company, Ltd., 35 Parliament Street, Westminster, London, Eng.	Nov. 12, 1889

Name.	Address.	Date of Election.
Wintringham, J. P.	Theorist, 36 Pine St , New York City, and 153 Henry St., Brooklyn, N.Y.	May 7, 1889
Wirt, Herbert C.	Engineer, Supply Department, General Electric Co., Schenectady, N. Y.	June 26, 1891
Woodward, Francke L.	Electrical Engineer, 49 Grand Street, Albany, N. Y.	June 26, 1891
Woodward, W. C.	Electrical Engineer, Narragansett Electric Lighting Co.; residence, 21 Arlington Ave., Providence, R. I.	Nov. 18, 1896
Woodworth, Geo. K	Instructor in Electrical Laboratory, Bliss School of Electricity, 35 B. St., N. W.; residence, 1424 St., N. W. Washington, D. C.	Feb. 17, 1897
Woolf, Albert E.	Electrician and Inventor, The Electrozone Co , 415 Lexington Ave., New York City.	Sept. 16, 1890
Worswick, A. E.	Electrical Engineer, Cape Town Tramways Company, Cape Town, So. Africa.	Sept. 20, 1893
Wotton, James A.	Electrician, Southern Bell Telephone and Telegraph Co., P. O. Box, 218, Atlanta, Ga.	Oct. 27, 1897
Wray, J. Glen	Assistant Engineer, Chicago Telephone Co., 162 Centre St., Chicago, Ill.	Sept 20, 1893
Wright, Louis S.	1700 Green St., Philadelphia, Pa.	Nov. 18, 1896
Wybro, Harrison C.	Electrical Engineer, Wybro & Lawrence Co., 53 Chronicle Building, San Francisco, Cal.	Dec. 18, 1895
Yarnall, V. H.	Superintendent of Construction, for L. W. Serrell, 99 Cedar St., New York City.	May 16, 1893
Young, Charles I.	Electrical Engineer, Westinghouse Elec. & Mfg. Co., Girard Building, Philadelphia, Pa.	June 27, 1895
Yslas, Carlos	Electrician of Railway in Jalapa, Vera Cruz, Mexico.	Nov. 18, 1896
Zalinski, Edmund L.	Captain of Artillery, U. S. A., (retired), The Century, 7 West 43d St., New York City.	May 17, 1887
Zimmerman, Laurence J.	Electrical Engineer and Inventor, 57 Pennsylvania Ave., Brooklyn, N. Y.	Mar. 21, 1893

(16) Associate Members, - - - - 749.

OFFICIAL STENOGRAPHER

Ryan, Richard W., Room 178, Post Office Building, Telephone, 2787 Cortlandt. Residence, 262 W. 11th St., New York City.

SUMMARY.

Honorary Members, - - - - - - - - -	2
Members, - - - - - - - - - - - -	351
Associate Members, - - - - - - -	749
Total - - - -	1102